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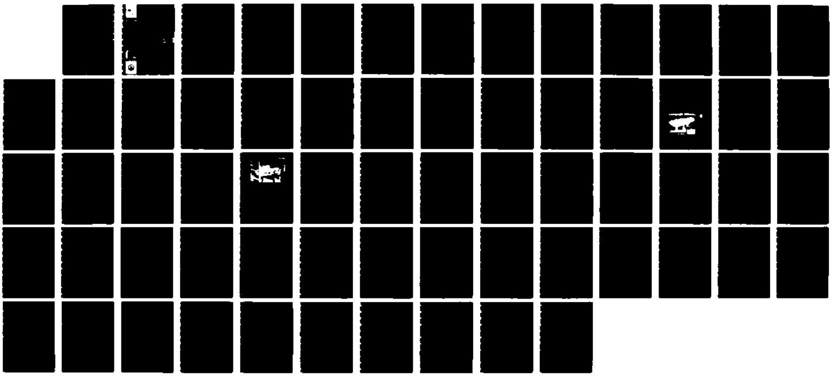

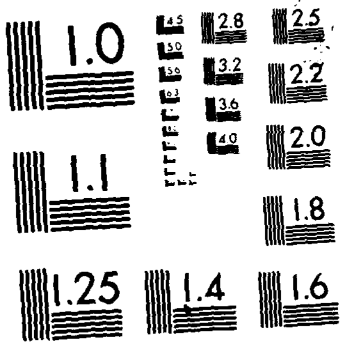

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TECHNICAL REPORT CERC-86-7

IRREGULAR WAVE OVERTOPPING OF SEAWALL/REVETMENT CONFIGURATIONS, ROUGHANS POINT, MASSACHUSETTS

Experimental Model Investigation

by

John P. Ahrens, Martha S. Heimbaugh, D. D. Davidson

Coastal Engineering Research Center

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Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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Laboratory tests to determine irregular wave overtopping rates on coastal structures were conducted at the Coastal Engineering Research Center in Vicksburg, Mississippi. These tests were intended to solve a site-specific problem at Roughans Point, Massachusetts. The results have yielded specific information for Roughans Point and a general approach to calculating irregular wave overtopping rates which is superior to the method given in the Shore Protection Manual (1984).

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PREFACE

The US Army Engineer Division, New England (NED), requested the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC) to conduct numerical and physical model studies to determine flood levels at Roughans Point, Massachusetts. Funding authorizations by NED were granted in Intra-Army Order No. 84-C-0031, dated 1 May 1984.

Physical model tests were conducted at CERC under general direction of Dr. R. W. Whalin, former Chief, CERC; Mr. C. E. Chatham, Chief, Wave Dynamics Division; and Mr. D. D. Davidson, Chief, Wave Research Branch. Tests were conducted by Messrs. Cornelius Lewis, Sr., Engineering Technician, and John Heggins, Computer Technician, under the supervision of Mr. John P. Ahrens, Oceanographer. This report was prepared by Mr. Ahrens, Mr. Davidson, and Ms. Martha S. Heimbaugh, Civil Engineer. Dr. James R. Houston was Chief and Mr. Charles C. Calhoun, Jr., was Assistant Chief, CERC, during the preparation and publication of this report. This report was edited by Ms. Shirley A. J. Hanshaw, Information Products Division, Information Technology Laboratory, WES.

Liaison was maintained with Mr. Charles Wener, Chief of NED's Hydraulics and Water Quality Section (HWQS), during the course of this study by means of conferences, progress reports, and telephone conversations. Mr. Donald Wood of the HWQS staff was sent to WES to assist in model testing and data analysis for a temporary assignment.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

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LIST OF FIGURES

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4046.873	square meters
cubic feet per second per foot	0.929	cubic meters per second per meter
feet	0.3048	meters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
square feet	0.09290304	square meters
tons (2,000 lb, mass)	907.1847	kilograms

IRREGULAR WAVE OVERTOPPING OF SEAWALL/REVETMENT CONFIGURATIONS, ROUGHANS POINT, MASSACHUSETTS

Experimental Model Investigation

PART I: INTRODUCTION

Background

1. This report discusses laboratory model tests of irregular wave overtopping for seawall and revetment configurations being considered for use at Roughans Point, Massachusetts (Figure 1). The tests were initiated by US Army Engineer Division, New England (NED), because of a lack of confidence in their wave overtopping estimates made by using the Shore Protection Manual (SPM) (1984). Roughans Point is a 55-acre* residential area which is partially protected from coastal flooding by seawalls on both its northern and eastern boundaries. The Roughans Point interior suffers damage from frequent flooding caused by the overtopping of seawalls. Laboratory tests discussed in this report were part of a more comprehensive study which included extensive use of computer models to calculate the frequency of occurrence of flood water levels for the interior of Roughans Point, along the open coast to the north, and for estuarine areas along the Saugus-Pines River system. The physical model tests provided wave overtopping coefficients only for the various seawall/revetment configurations used in the numerical flood routing model for the interior of Roughans Point. Water level calculations for the coastline north of Roughans Point and the estuarine areas did not include consideration of wave overtopping. For further information about the computer models and the organization of the entire study see Hardy and Crawford (in preparation). The model tests described in this report were conducted primarily to develop methods to reduce wave overtopping of the eastern seawall (Figure 2, Reach E), to determine objective criteria for judging the effectiveness of the methods to reduce overtopping, and to provide wave overtopping coefficients to the numerical flood routing model.

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* A table of factors for converting non-SI to SI (metric) units is presented on page 3.

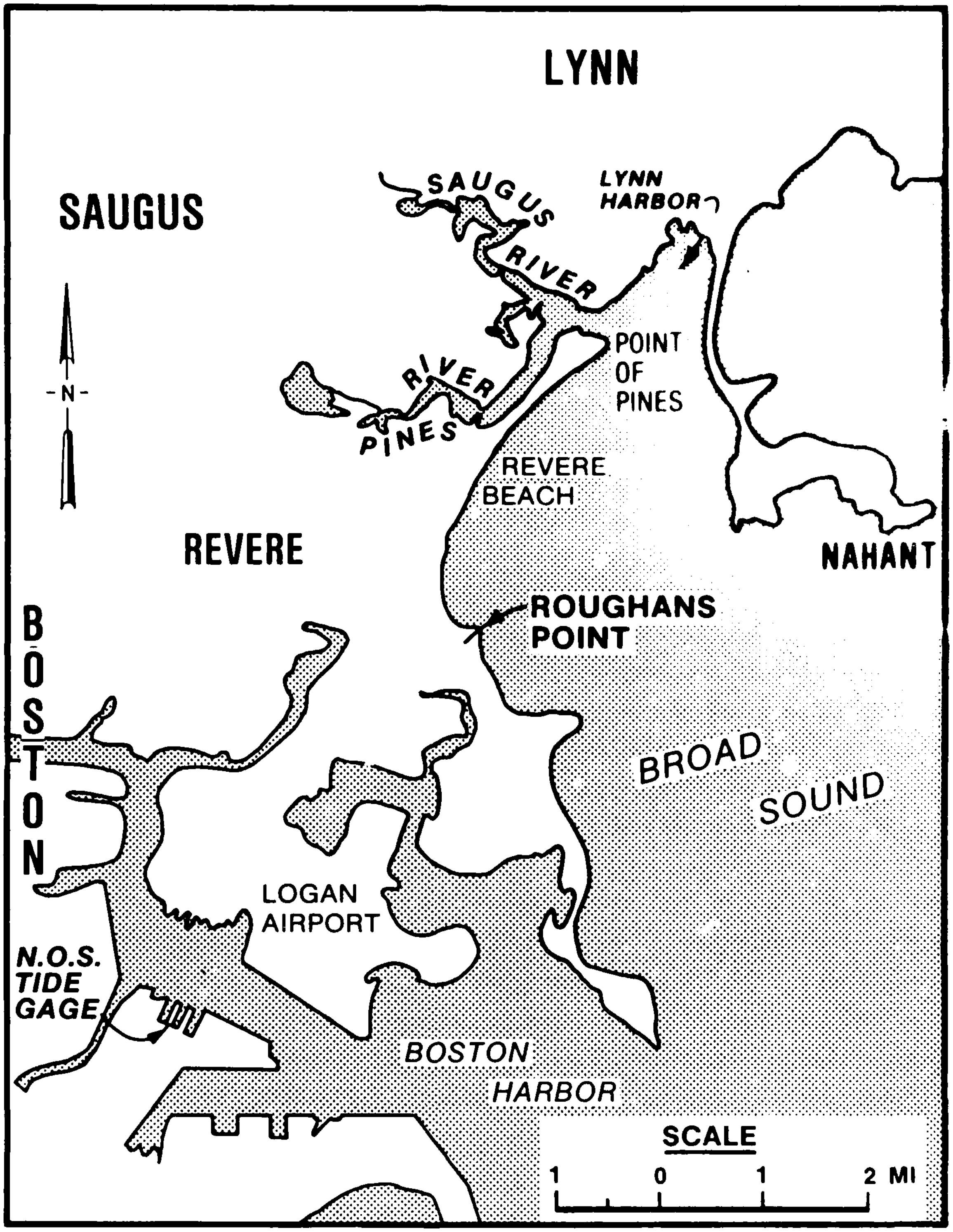


Figure 1. Location and vicinity map

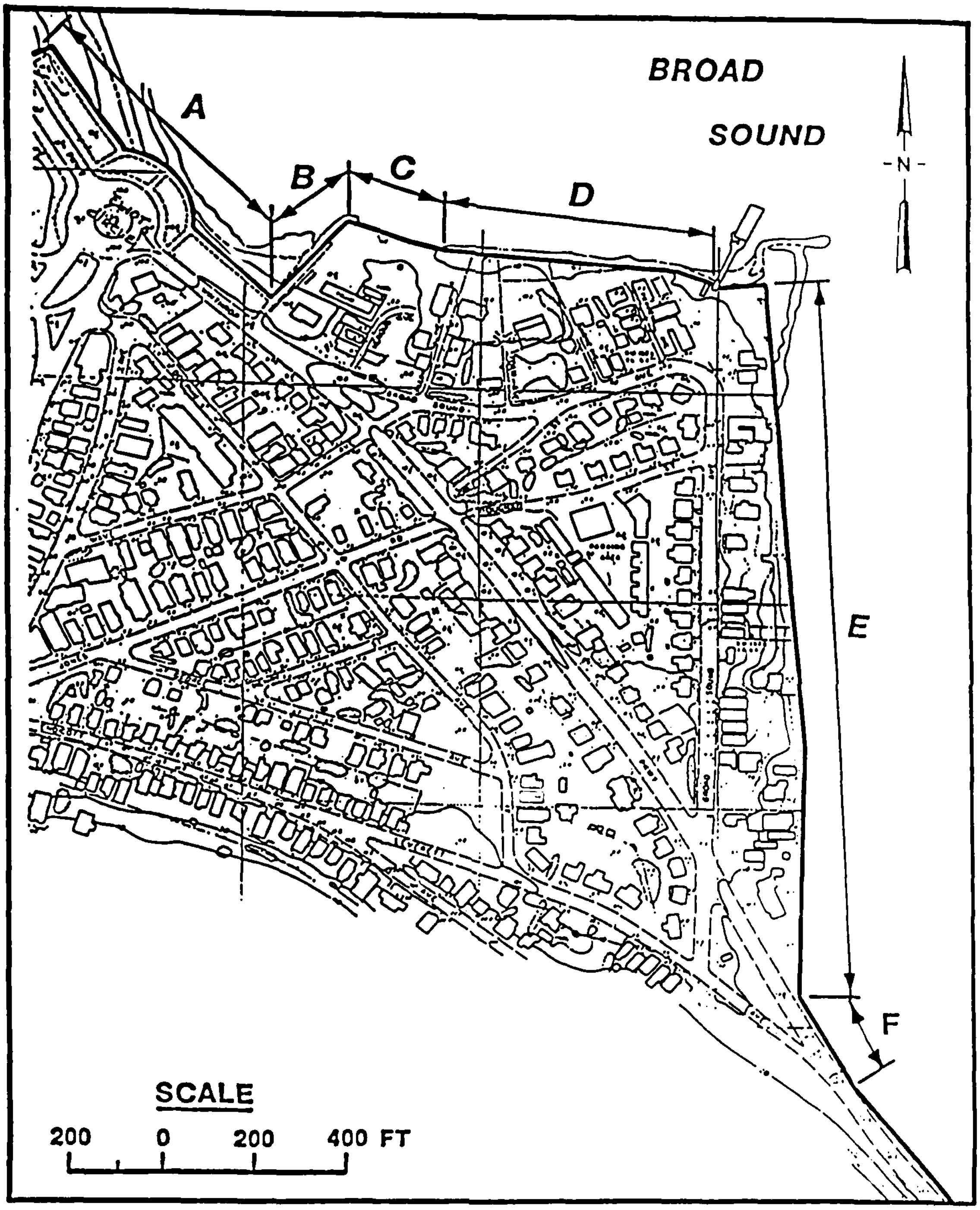


Figure 2. Location of Reaches A through F at Roughans Point

2. A number of different revetment configurations were constructed in front of the Roughans Point seawall, and the wall crest elevation was varied to determine their ability to reduce wave overtopping of the wall. Results of this effort have yielded specific information to help solve the Roughans Point site-specific problem and general information which will help to improve current techniques for calculating irregular wave overtopping rates given in the SPM (1984). A simple way to quantify the overtopping potential of the various seawall/revetment configurations is presented.

Purpose

3. The purposes of this two-dimensional (2-D) wave overtopping study were to:

a. Evaluate the effectiveness of 10 proposed seawall/revetment configurations at reducing wave overtopping of the Roughans Point seawall.

b. Determine a simple method to predict wave overtopping of the Roughans Point seawall.

PART II: THE MODEL

Model Design

4. Model tests were conducted in a wave tank 3 by 3 by 150 ft long. This tank had a hydraulically actuated piston wave blade which was controlled by an Automatic Data Aquisition Control System (ADACS) computer. In order to reduce scale effects, the largest scale consistent with the available facilities was used. The undistorted Froude scale used was 1:16 (model:prototype). Although this study was primarily concerned with overtopping rates for various seawall/revetment configurations, armor stone size distributions for the model revetments were carefully determined to correspond with prototype sizes designed by NED in their planning studies (NED 1982). Based on Froude's Model law (Stevens 1942) and the linear scale of 1:16, the following model-to-prototype relations were derived (dimensions are in terms of length (L) and time (T)):

Characteristic	Dimension	Model-to-Prototype Scale Relations
Length	L	$L_r = 1:16$
Area	L^2	$A_r^2 = 1:256$
Volume	L^3	$V_r = L_r^3 = 1:4,096$
Time	T	$T_r = L_r^{1/2} = 1:4$

5. The specific weight of fresh water used in the model was assumed to be 62.4 pcf and that of seawater 64.0 pcf. The specific weight of armor stone used in the model and that proposed for the prototype was 165 pcf. These variables are related using the following transference equation:

$$\frac{(W_a)_m}{(W_a)_p} = \frac{(\gamma_a)_m}{(\gamma_a)_p} \left(\frac{L_m}{L_p}\right)^3 \left[\frac{(S_a)_p - 1}{(S_a)_m - 1}\right]^3$$

where

W_a = weight of an individual armor stone, lb

m, p = model-to prototype quantities, respectively

γ_a = specific weight of an individual armor stone, pcf

L_m/L_p = linear scale of model

S_a = specific gravity of an individual armor stone relative to the water in which the breakwater is constructed, i.e., $S_a = \gamma_a/\gamma_w$

γ_w = specific weight of water, pcf

Model armor stone sizes ranged from 0.38 to 0.70 lb with a median weight of 0.55 lb for all configurations tested except one, Configuration 9, which used armor stone ranging from 0.593 to 1.431 lb with a median weight of 1.0185 lb. Applying the above transference equation, the equivalent range of weights tested was from 1,745 to 3,255 lb in the prototype, with a median weight of 2,551 lb prototype, and from 2,747 to 6,629 lb in the prototype, with a median weight of 4,718 lb, respectively.

Model Conditions and Testing Procedures

Wave tank calibration

6. A 1V on 100H slope was selected as representative of the Roughans Point bathymetry seaward of the eastern seawall. Using this bathymetry, wave conditions in the wave tank were measured at various locations using parallel wire resistance wave gages but without any seawall/revetment plan in place. Figure 3 shows the location of the gages. This setup allowed calibration of the wave tank apparatus without significant wave reflections, which is analogous to wave forecast by hindcast procedures.

7. During the initial tests of Configuration 1 (vertical seawall with no fronting revetment) severe wave reflections were created in the tank because of the vertical wall. To eliminate this reflection, the tank was divided into two sections, one containing the test structure and the other containing a wave absorber to reduce the unnatural wave tank reflections. Figures 4 and 5 show plan and profile views of the partitioned sections of the wave tank for the final tests conducted on Configuration 1. Dividing of the tank significantly reduced the wave tank reflections for all test conditions; thus, it was decided Gage 7 in the wave absorber channel could be used to measure the incident wave conditions rather than depend on the original calibration data. Gage 7 was used to measure the incident zero-moment wave height H_{mo}, but the period of peak energy density T_p was assummed on the basis of

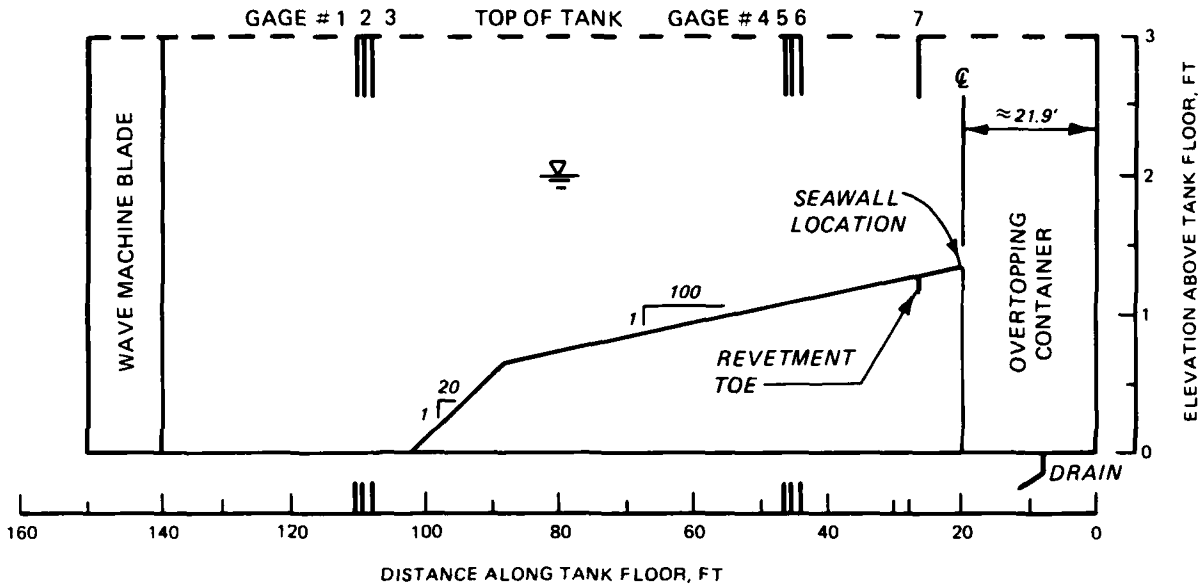


Figure 3. Wave gage location in 3- by 3- by 150-ft-long wave tank

conservation of wave period to be the period that was programmed to be generated by the wave machine and therefore will be referred to as the nominal T_p .

Test conditions

8. A wide range of wave conditions was represented in these tests. The periods of peak energy density T_p tested were 5, 7, 8, 9, 10, and 12 sec in the prototype. The still-water levels (swl) tested ranged between about +8.58 and +10.80 ft National Geodetic Vertical Datum (NGVD). The tests produced local zero-moment wave heights ranging from about 2.5 to 9.0 ft with most heights in the 5- to 8-ft range. Tabulated test conditions and data results are given in Appendix A.

Test procedures

9. During a single test run, irregular waves were generated continuously for 33 min. The ADACS was programmed to produce a modified Joint North Sea Wave Program (JONSWAP) wave spectrum for the water depth at the wave blade. Water depths at the wave blade ranged from about 32.0 to 35.0 ft. JONSWAP spectra tend to be rather narrow (Hasselmann et al. 1973), in that a large portion of the total energy is concentrated near the frequency associated with the period of peak energy density T_p . Since wave shoaling and breaking were very conspicuous between the wave blade and structure for most

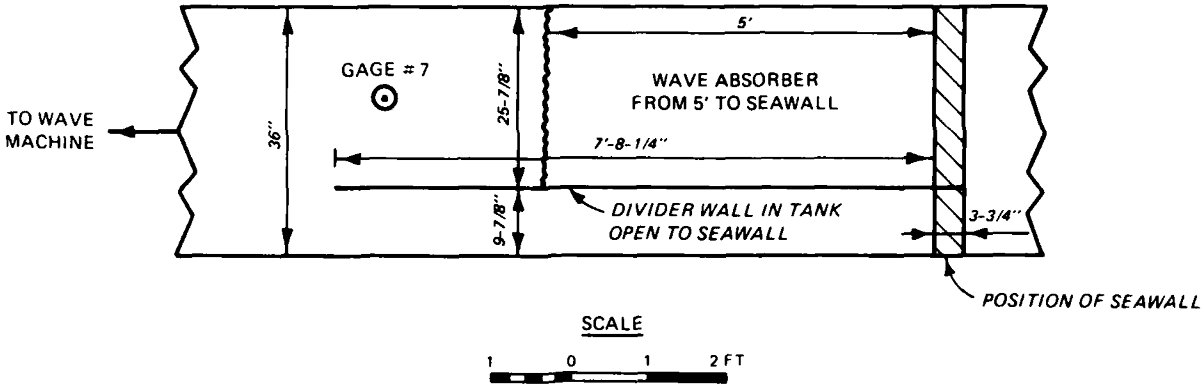


Figure 4. Plan view of Configuration 1, seawall with no fronting revetment

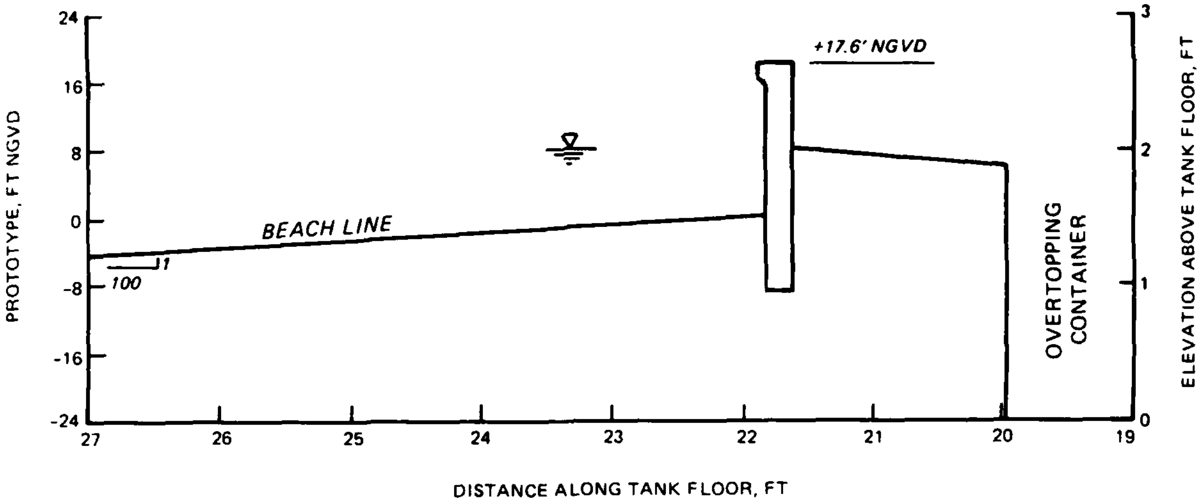


Figure 5. Configuration 1, seawall with no riprap revetment

of the tests, the wave conditions in front of the seawall do not have a JONSWAP spectrum but represent a wider type of spectrum.

10. Overtopping rates were determined by measuring the change in water level in the overtopping container behind the seawall during a test run. If overtopping rates were high, water was added to the seaside portion of the flume during the test run to compensate for the water lost over the wall and to maintain an approximately constant water level seaward of the seawall. Water levels were measured to the closest one thousandth of a foot before and after a test run, both in the overtopping container and the offshore portion of the wave tank, using point gages.

11. Information data presented in all the data tables are given in prototype dimensions. Table 1 is a list of the various seawall/revetment configurations tested during this study with figure and plate numbers that correspond to their descriptions and data plots, respectively. Also note that the underlayer sizes shown in the cross-sectional figures are oversized in order to compensate for scale effects present in the model.

Table 1

List of Various Seawall/Revetment Configurations, Figure Numbers, and Overtopping Coefficients

Configuration Designation Number	Description of Seawall/Revetment Configuration	Figures Showing Configuration	Plates Showing Data	Overtopping Coefficients: Regression Q_o C_1	Overtopping Coefficients: Nonregression Q_o C_1	Configuration Overtopping Rating Coefficient, A^q: Regression	Configuration Overtopping Rating Coefficient, A^q: Nonregression
1	Existing Roughans Point seawall with no riprap revetment	5	1	76.554 -14.078		0.0797	
2*	Roughans Point seawall with standard riprap revetment	6,7	2	30.539 -13.431		0.0404	
3	Roughans Point seawall with a wave absorber riprap revetment	10	3	485.413 -20.845		0.0448	
4	Roughans Point seawall with riprap revetment having a wide berm at +8 ft NGVD	11	4	1,157.479 -25.461	439.220 -21.621	0.0219	0.0310
5	Roughans Point seawall with riprap revetment having a double berm at +6 and +10 ft NGVD	13	5	758.240 -25.226		0.0155	
6	Roughans Point seawall with riprap revetment having a berm at +10 ft NGVD and 1.0-ft cap on seawall	14	6	353.541 -23.943		0.0112	
7	Roughans Point seawall with riprap revetment having a wide berm at +8 ft NGVD and a 1.0-ft cap on seawall	15	7	57.628 -19.569	305.821 -23.073	0.0083	0.0131
8	Roughans Point seawall with riprap revetment having a wide berm at +8 ft NGVD and a 2.0-ft cap on seawall	16	8	93.037 -22.154		0.0055	
9	Roughans Point seawall with beach breakwater	18	9	15.226 -14.410	109.508 -18.654	0.0140	0.0218
10	Sheet-pile seawall with standard riprap revetment, designed for less severe wave conditions	20	10	75.189 -17.783		0.0204	

* Plan recommended by NED in planning investigations (NED 1982).

PART III: PRESENTATION OF RESULTS

Development of Overtopping Parameters

12. One of the most important findings of this study was the development of a dimensionless relative freeboard parameter F' which consolidated all of the data for one structure configuration into a single trend. The term, F' is defined

$$F' = \frac{F}{\left(H_{mo}^2 \quad L_p\right)^{1/3}} \tag{1}$$

where F is the freeboard, i.e., the difference between the crest height of the seawall and the local SWL, and L_p is the Airy wave length calculated using the water depth at Gage 7 and the nominal T_p . Equation 1 can be thought of as the ratio of the freeboard and the severity of the local wave action. The term F' combines a large amount of information into one parameter which contains the seawall crest elevation, the local water depth or water level, the zero-moment wave height, and the period of peak energy density of the spectrum through the use of L_p . This parameter, F' , seems to consolidate the data into a single trend better than other variables, including the parameter F/H_{mo} suggested by the work of Goda (1969) and Seelig (1980) or the dimensionless freeboard parameter $F/(T_z g H_s)$ used by Owen (1982), where T_z is the zero-crossing wave period, H_s is the significant wave height, and g is the acceleration of gravity. Using L_p in the F' parameter seems to be a very effective way to account for wave period effects which are conspicuous when observing the laboratory tests. After a short time of model observation, it was obvious (other factors being equal) that the larger the T_p of the spectra the greater the overtopping.

13. Following the rationale given above, the overtopping rate Q is plotted versus F' (Plates 1-10) for all of the seawall/revetment configurations given in Table 1. The overtopping rate Q is defined as the volume of water overtopping the seawall per unit length of seawall per unit time. For this study, Q is given in units of cubic feet per foot per second. Also shown in Plates 1 through 10 is a regression curve which has been fit to the

data shown in the respective plate. On some plates a second curve (nonregression) has been added. The second curve has been added where the data scatter suggests that for design purposes a trend more conservative than the regression curve should be used. The second curves are not regression curves but are curves that have been fit by eye on the basis of the judgment of the principal investigators. Where both curves are present the nonregression curve is the one that is recommended for use for design purposes. It should be noted that various vertical scales have been used in Plates 1-10. The vertical scales were chosen to help portray the observed data effectively, but the scales make direct comparisons between these plates difficult. Comparisons between various configurations are made later in the text.

14. All of the curves shown in Plates 1-10 have been fit to an equation of the general form

$$Q = Q_o e^{C_1 F'} \tag{2}$$

where C_1 is a dimensionless coefficient, and Q_o is a coefficient with the same units as Q (ft^2/sec). The coefficients have been determined either by regression analysis or "fit by eye" as mentioned above. Equation 2 seems to have the proper form to fit all of the data sets rather well and is the same form as the overtopping equation developed by Owen (1982) in his laboratory study of irregular wave overtopping of sea dikes. Coefficients Q_o and C_1, for both regression and nonregression curves, are given in Table 1.

15. Although the parameter F' given by Equation 1 and used as the independent variable for Plates 1-10 may seem a bit abstract at first, it is effective in consolidating the data into well defined trends that can be readily identified. Generally, there is a large change in Q in the range of F' between 0.3 and 0.5. For F' greater than 0.5 there is little wave overtopping, while for F' less than 0.3 there is considerable overtopping regardless of the seawall/revetment configuration.

16. These large amounts of wave overtopping result from the effect of large waves hitting the seawall or seawall/revetment at high water levels. The term high waves means those with crest elevations probably in the range of 70 to 80 percent of the freeboard. For these conditions it is difficult to envision a strategy which would be effective. The wave just surges up at the wall and inundates the recurve then spills over the crest of the seawall in

large masses of "green" water. It is hard to imagine any surface feature of the wall or fine tuning of the fronting revetment being particularly effective for this extreme situation. For the tests conducted in this study, the inundation mode of overtopping occurred primarily when F' was less than about 0.3. Because changes in the geometry of the various seawall/revetment configurations is not very important when overtopping is in the inundation mode, it was not deemed necessary to make comparisons of data trends for F' less than 0.3.

17. One simple way to evaluate the effectiveness of a seawall/revetment configuration is to use the area under the data trend curve. The less area under the curve the more effective the configuration. Because of the discussion given above, a logical lower limit for integration is 0.3, although other limits could be used. The overtopping ranking coefficient A_q is defined

$$A_q = Q_o \int_{F'_{min}}^{\infty} e^{C_1 F'} \, dF' = - \frac{Q_o}{C_1} e^{C_1 F'_{min}} \qquad (3)$$

A_q is shown in Table 1 using $F'_{min} = 0.3$. As with any complex phenomenon no single parameter can be used to evaluate performance without considerable care; but because this parameter seems to be such a logical extension of the method of computing overtopping rates developed in this report, it is presented here. When evaluating structures, the smaller the value of A_q the more effective the seawall configuration.

18. At the request of NED, overtopping coefficients and overtopping ranking coefficients were calculated for a previous monochromatic wave overtopping study conducted by Saville (1955). Discussion of this effort and tabulation of the coefficients are given in Appendix B.

Stability of Armor Stone

19. All configurations tested used the 2,551-lb median stone weight, except Configuration 9 which used 4,718-lb medium stone weight (as described in paragraph 5). Occasionally during testing, one or two armor stones would be dislodged, but this movement was not significant; and the armor stone for all configurations, except the double berm in Configuration 5 was observed to

be stable for all swl/wave conditions tested. The double berm in Configuration 5 merged into a single slope and then stabilized. The armor slope for Configuration 6 was purposely constructed similiar to the stabilized slope in Configuration 5 and proved to be stable throughout the testing of Configuration 6. With the exception of Configuration 5, armor stone movement for all configurations was not significant, with only one or two stones being dislodged after long periods of wave attack. Thus the stone size represented in the model should be satisfactory for any storms within the conditions tested.

PART IV: DISCUSSION

20. It was found that a standard riprap revetment (Configuration 2) in front of the seawall (Figures 6 and 7 and Plate 2) reduced wave overtopping rates in the range of 40 to 50 percent over what was expected to overtop in the absence of the revetment (Configuration 1, Plate 1). A comparison of the data trends for Configuration 1 and 2 is given in Figure 8. In general, the standard revetment did not reduce overtopping rates very effectively. Two problems, which were not detected prior to the test, can be identified with the standard revetment:

a. If the top of the revetment is too high, it interferes with the recurve causing the recurve not to function effectively.

b. If the revetment acts as a ramp, which it often does, it causes the waves to ride up and over the wall without a major discontinuity in the flow. This "ramp effect" is pictured in Figure 9.

21. The wave absorber revetment (Configuration 3, Table 1, and Figure 10) was an attempt to make the revetment a better wave absorber by adding armor stone. Configuration 3's performance (Plate 3) was poor because it was not recognized at that point how important it was to maintain discontinuities in the configuration, such as the recurve and the wall itself, to disrupt the wave action and runup flow. In designing Configuration 3, the main goal was to try to dissipate as much wave energy as possible within the spatial constraints.

22. The revetment with a wide berm at +8 ft NGVD (Configuration 4, Table 1, and Figure 11) was designed to provide a discontinuity to wave action and runup flow, to allow the recurve to function effectively, and to still be a good dissipator of wave energy. Configuration 4 results (Plate 4) show it to be a very effective design in reducing overtopping, and its performance is better compared to the standard revetment (Configuration 2 in Figure 12).

23. Configuration 5 (Table 1 and Figure 13), with a double berm, was an attempt to fine tune the idea developed in Configuration 4. The slope connecting the two berms was 1V on 2H and was not stable with the more severe wave conditions. As a consequence, the two berms had merged into a single, somewhat sloped, berm by the end of the tests. Configuration 5's performance (Plate 5) indicates it was effective in terms of reducing overtopping, but the need for two berms is probably not worth the added design and construction complexity. A single rather flat slope between +6 and +10 ft NGVD probably

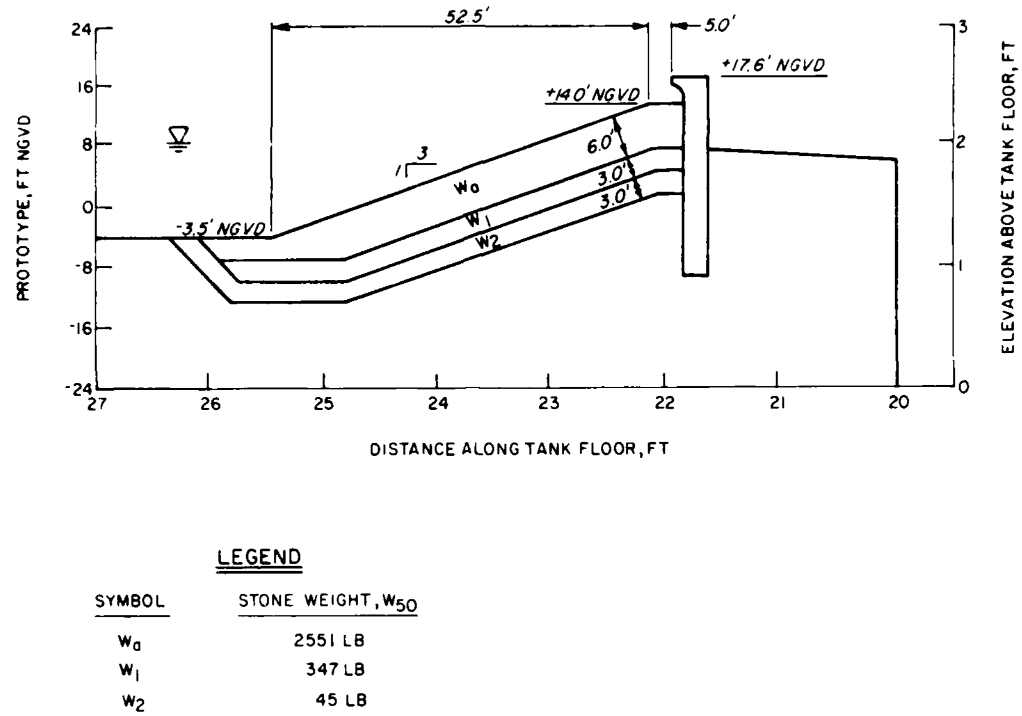


Figure 6. Configuration 2, seawall with standard riprap revetment

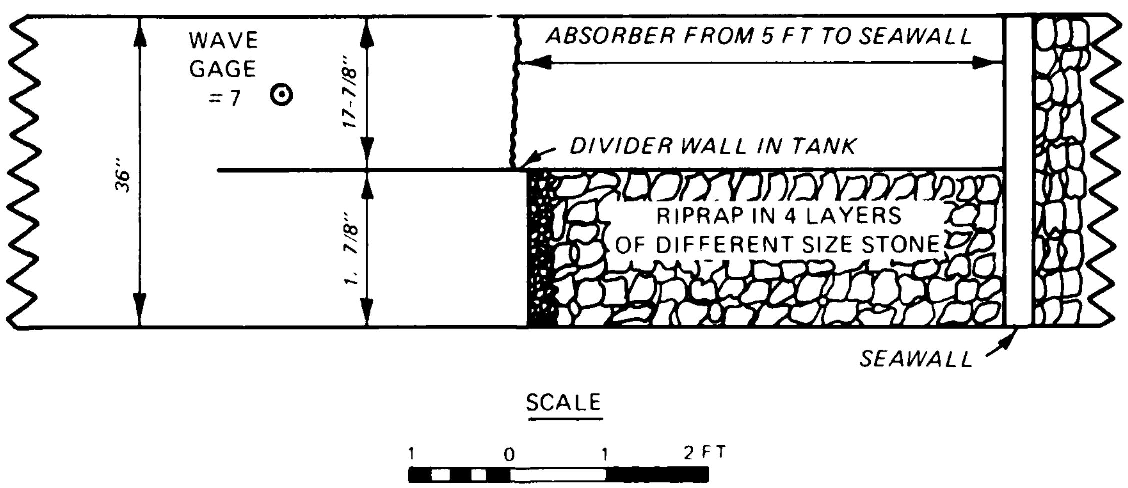


Figure 7. Plan view of Configuration 2 in wave tank

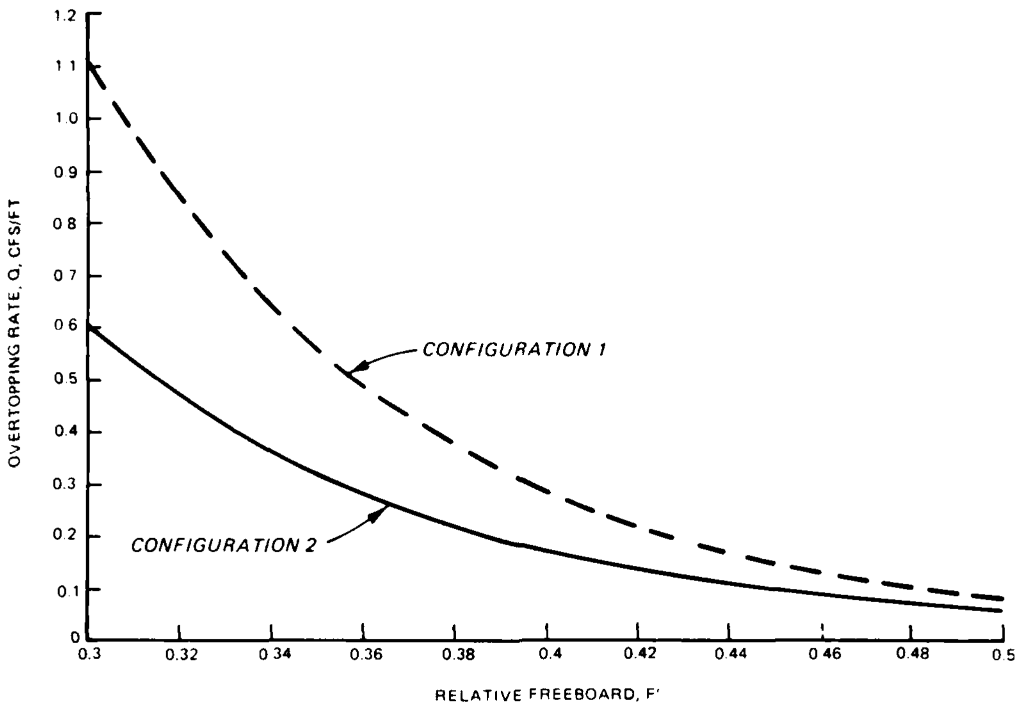


Figure 8. Comparison of data trends for Configurations 1 and 2

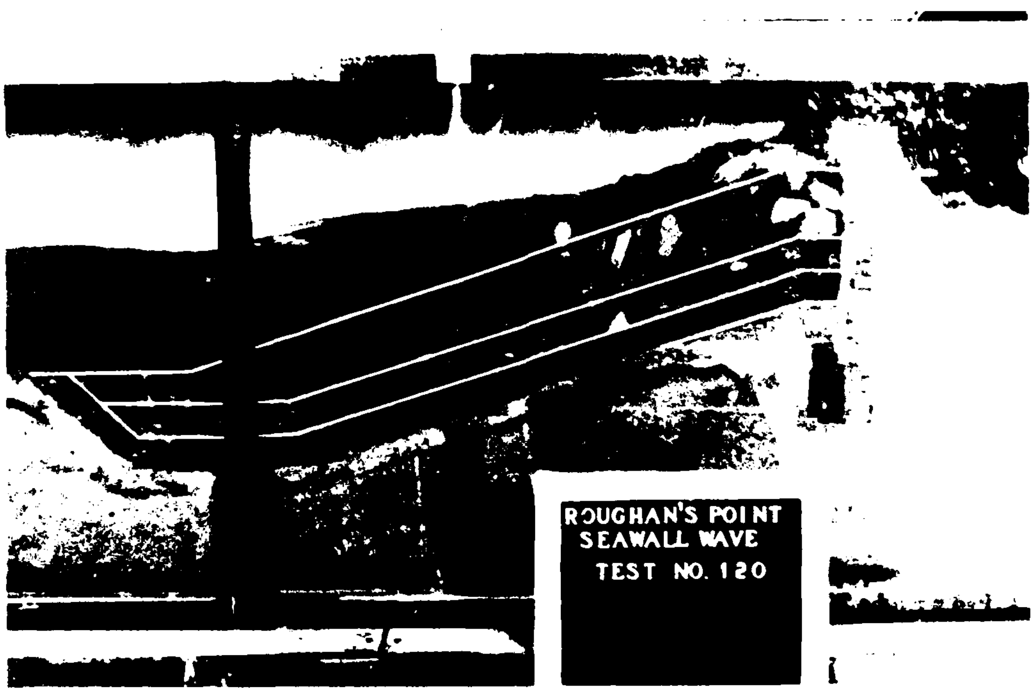
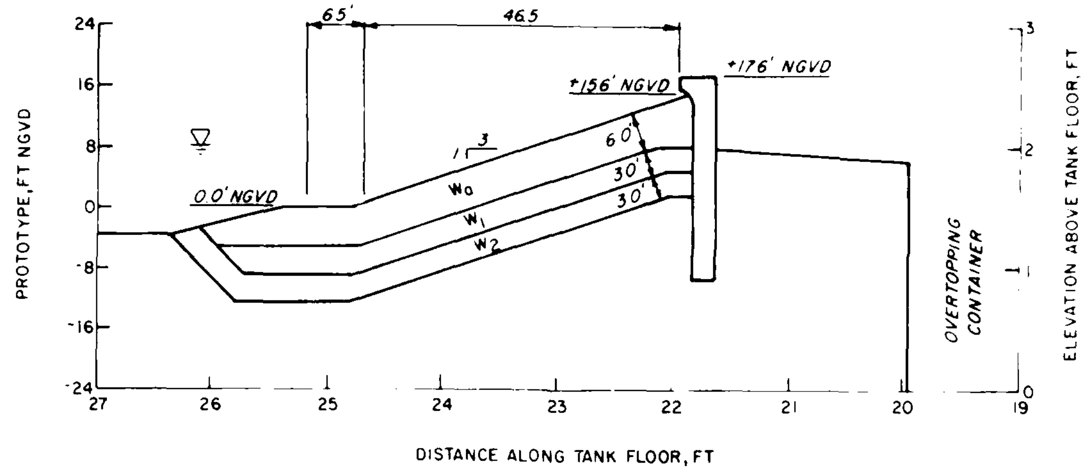


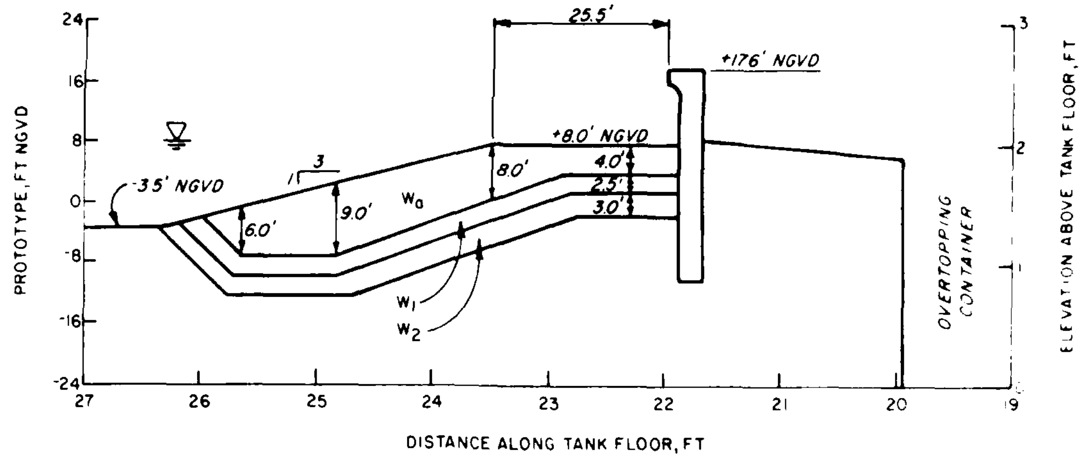
Figure 9. Configuration 2, seawall with standard riprap revetment as it appeared in the model study



LEGEND

SYMBOL	STONE WEIGHT, W_{50}
W_a	2551 LB
W_1	347 LB
W_2	45 LB

Figure 10. Configuration 3, seawall with a wave absorber riprap revetment



LEGEND

SYMBOL	STONE WEIGHT, W_{50}
W_a	2551 LB
W_1	347 LB
W_2	45 LB

Figure 11. Configuration 4, seawall with riprap reve'ment having a wide berm at +8 ft NGVD

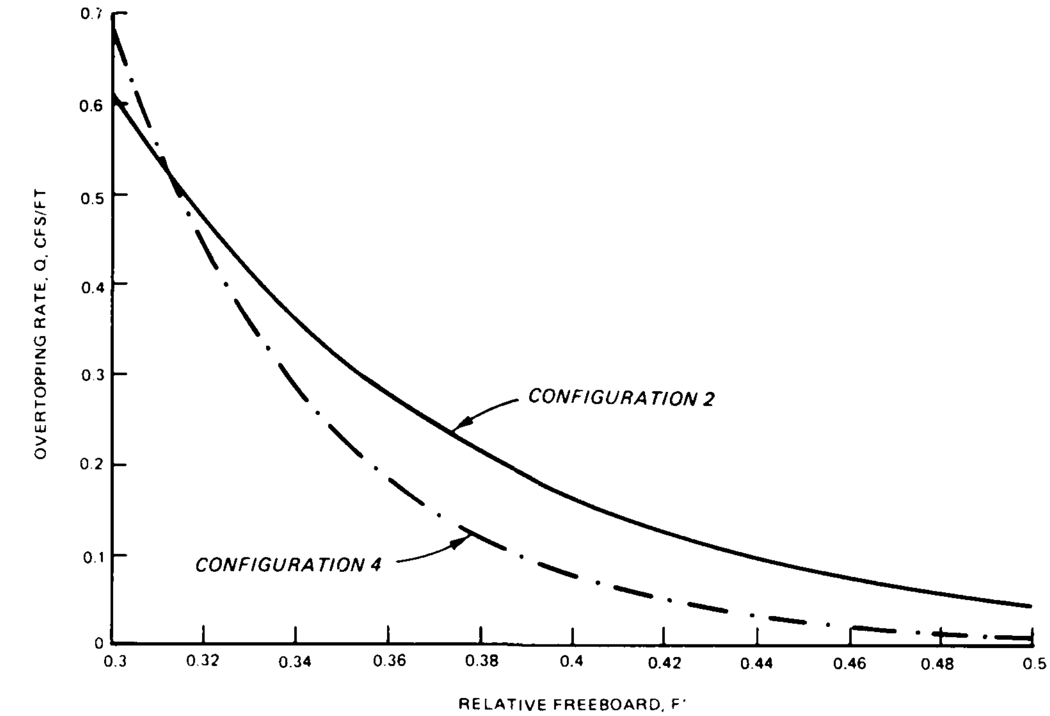
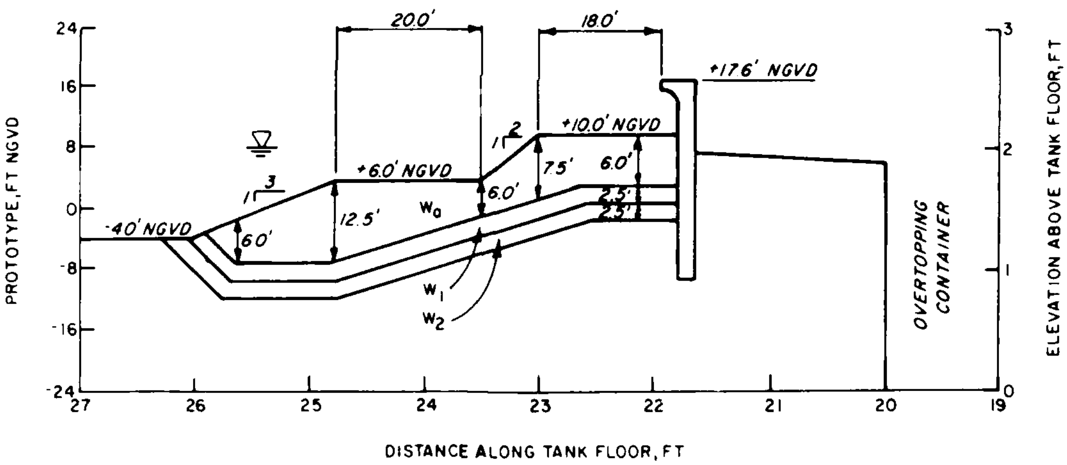


Figure 12. Comparison of data trends for Configurations 2 and 4



LEGEND

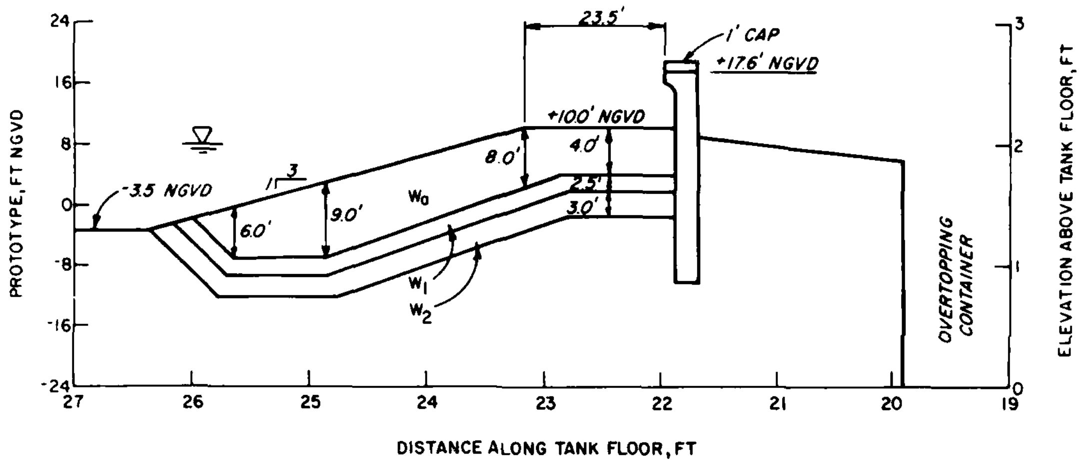
SYMBOL	STONE WEIGHT, W_{50}
W_a	2551 LBS
W_1	347 LBS
W_2	45 LBS

Figure 13. Configuration 5, seawall with riprap revetment having a double berm at +6 and +10 ft NGVD

would have been just as effective as the double berm. Problems with armor stability would not have been encountered, and construction would be easier.

24. Configurations 6, 7, and 8 (Table 1 and Figures 14, 15, and 16) use a combination of fronting revetment and a cap on the seawall in an effort to further reduce overtopping rates. Data plots of Q versus F' for each of these configurations are given in Plates 6, 7, and 8, respectively. Since all the data trends indicate that there is an approximately exponential relation between the freeboard and overtopping rates, adding a cap (vertical height) to the seawall would be an effective means of reducing wave overtopping. Figure 17 shows a comparison of data trends for Configurations 1, 4, 7, and 8 in which Configuration 1 is a seawall with no revetment and Configurations 4, 7, and 8 represent a revetment having a wide berm at +8 ft NGVD and a seawall with no cap, a 1.0-ft cap, and a 2.0-ft cap, respectively. These data show that a wide berm revetment (Configuration 4) is better than no revetment (Configuration 1), but Configuration 4 can be made more effective by adding height to the wall (Configurations 7 and 8). One way to think about the effectiveness of added wall height is to consider the amount of stone that would have to be placed in front of the seawall to obtain a similar amount of reduction in overtopping as a 1.0-foot cap on the seawall. Although Figure 17 does not answer this question quantitatively, it suggests that a 1.0-ft cap is equivalent to a significant amount of stone in front of the seawall. The coefficients given in Table 1 and the curves drawn using the coefficients were computed using a seawall crest height of 17.6 ft NGVD in all cases. This approach is rather like treating the cap as just additional stone to dissipate wave energy and is necessary to compare the effectiveness of various configurations with various seawall crest elevations. In principle, the performance of a cap (added wall height) can be anticipated using Equations 1 and 2 and test data for a configuration without a cap, but this approach was not tried because of lack of confidence in the ability to extrapolate results using such a new method of predicting overtopping rates.

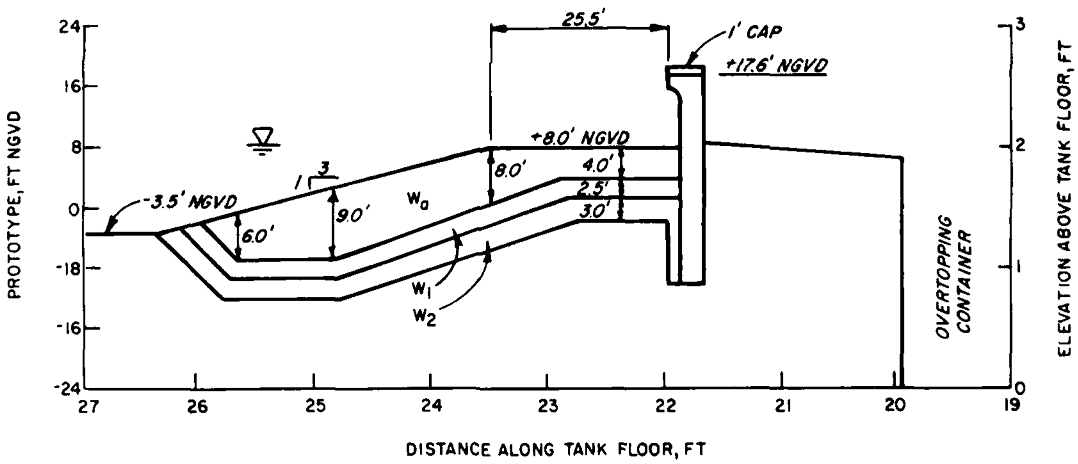
25. Configuration 9 (Table 1 and Figure 18) is an attempt to evaluate the ability of an offshore breakwater to reduce wave overtopping without going very far offshore. Since the breakwater was so close to the seawall, it is referred to as a beach breakwater in Table 1. The beach breakwater was relatively effective at reducing overtopping (Plate 9) but even so, its performance seemed to be something of a disappointment. The appearance of the



LEGEND

SYMBOL	STONE WEIGHT, W_{50}
W_a	2551 LB
W_1	347 LB
W_2	45 LB

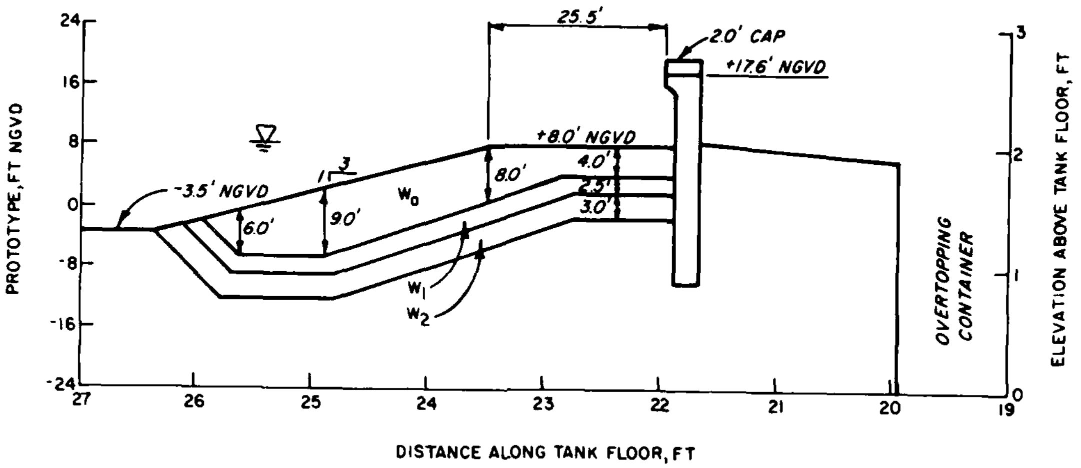
Figure 14. Configuration 6, seawall with riprap revetment having a berm at +10 ft NGVD and 1.0-ft cap on seawall



LEGEND

SYMBOL	STONE WEIGHT, W_{50}
W_a	2551 LB
W_1	347 LB
W_2	45 LB

Figure 15. Configuration 7, seawall with riprap revetment having a wide berm at +8 ft NGVD and a 1.0-ft cap on seawall



LEGEND

SYMBOL	STONE WEIGHT, W_{50}
W_a	2551 LB
W_1	347 LB
W_2	45 LB

Figure 16. Configuration 8, seawall with riprap revetment having a wide berm at +8 ft NGVD and a 2.0-ft cap on seawall

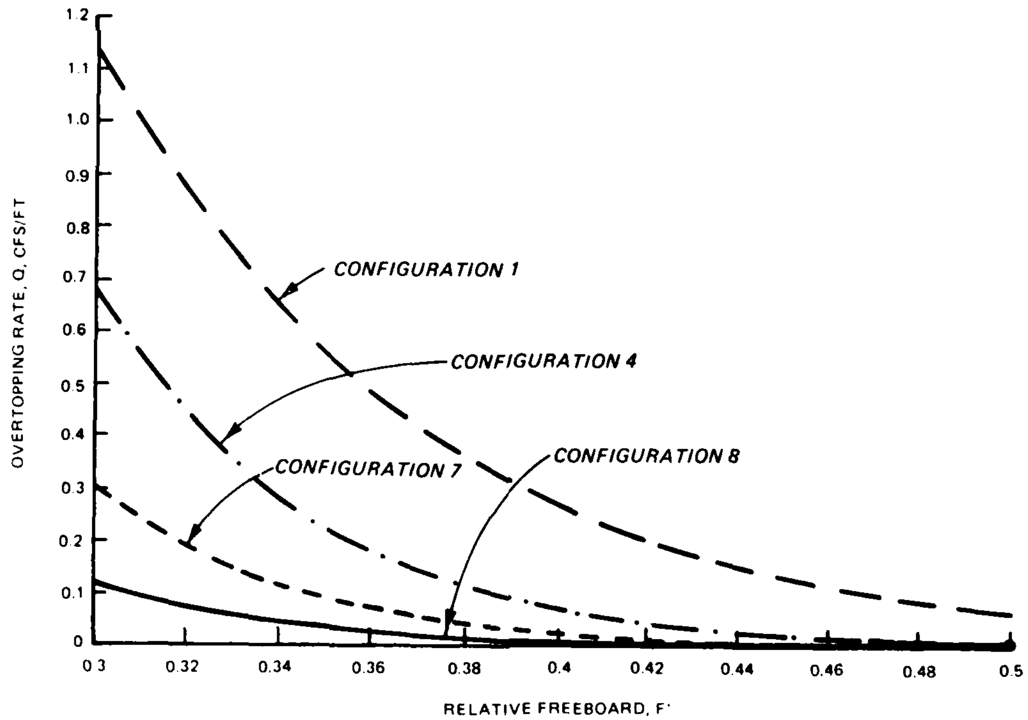
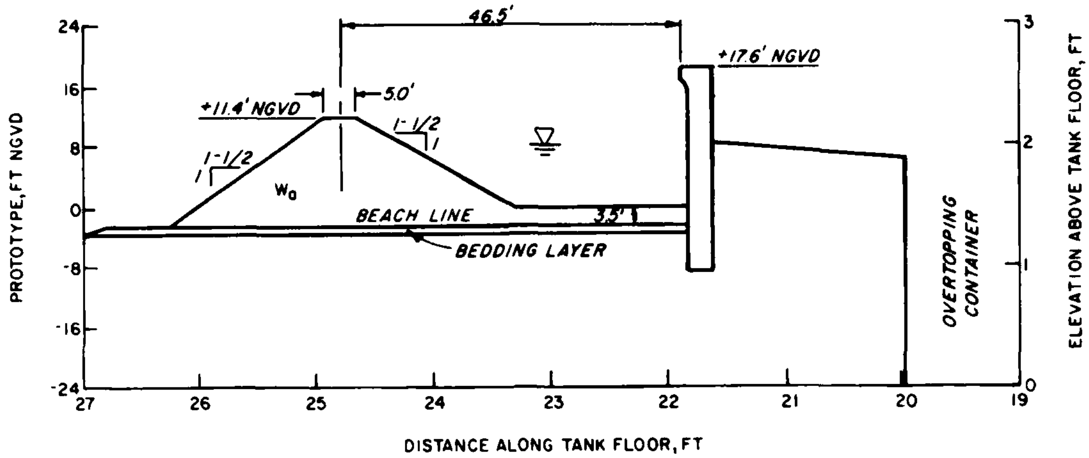


Figure 17. Comparison of data trends for Configurations 1, 4, 7, and 8



LEGEND

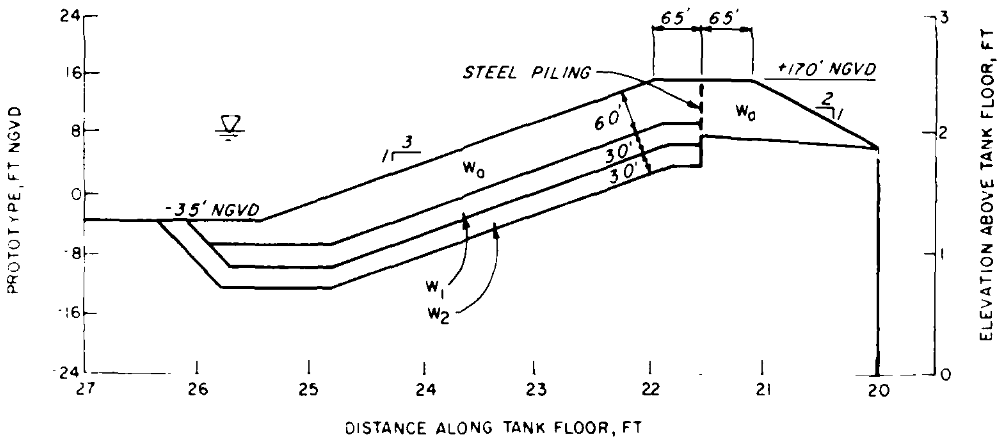
SYMBOL	STONE WEIGHT, W_{50}
W_a	4718 LB

Figure 18. Configuration 9, seawall with beach breakwater

beach breakwater and the seawall inspired considerable confidence since both represent formidable discontinuities to waves and runup flow and a considerable amount of armor stone was used to dissipate wave energy. Figure 19 shows how the beach breakwater appeared in the model study. It appears that one problem with the beach breakwater was the lack of distance between the breakwater and the seawall to dissipate as much wave energy as could potentially be achieved from all the turbulence that was introduced by the breakwater. However, if the breakwater were moved farther offshore it would be in deeper water and therefore require a larger structure making construction more difficult. There is also the problem that the breakwater requires larger armor stone because it has to be built with steeper side slopes than the revetment in order to fit into the allocated space. In addition, the beach between the breakwater and the seawall needs to be armored to prevent scour. Probably because of the roughness and high porosity of all the armor stone there was no tendency for wave resonance to be observed in the pond formed between the breakwater and seawall. The added complexity of building a beach breakwater compared to a revetment against the seawall suggests that the breakwater would not be cost effective.

26. Configuration 10 (Table 1 and Figure 20) is a sheet-pile seawall with a standard riprap revetment fronting it. A plot of Q versus F' for

Figure 19. Configuration 9, seawall with beach breakwater as it appeared in the model study



LEGEND

SYMBOL	STONE WEIGHT, W_{50}
W_0	2551 LB
W_1	347 LB
W_2	45 LB

Figure 20. Configuration 10, sheet-pile seawall with standard riprap revetment designed for less severe wave conditions

Configuration 10 is presented in Plate 10. This configuration has offshore water depths somewhat shallower than those for the other configurations. It was being considered for sheltered areas along Broad Sound (Reaches A through D, Figure 2) and was not intended for use on the open coast (see Hardy and Crawford (in preparation) for details related to the strategy for reducing flooding at Roughans Point). In the model the shallower offshore depths were achieved by lowering the reference water level 1.6 ft. As a result there is greater truncation of the large waves in the wave height distribution for this configuration than for the other configurations, and the results cannot be compared. Attempting to compare the results leads to the conclusion that a standard revetment fronting a sheet-pile seawall is unusually effective in reducing wave overtopping when contrasted to a standard revetment fronting the recurved seawall. The reason for the anomaly appears to be that overtopping rates are unusually sensitive to a few large waves, and there are not many of these large waves because of the shallow offshore water depths used for Configuration 10.

PART V: SUMMARY AND CONCLUSIONS

27. A number of revetment configurations were tested for effectiveness in reducing irregular wave overtopping of the Roughans Point seawall. Results of the study are summarized in Figures 21 and 22. The tests indicate that a standard riprap revetment in front of the wall with the top of the riprap close to the top of the wall (Configuration 2, as recommended by NED) is not the most effective configuration for reducing overtopping. Configuration 4, a riprap revetment with a relatively wide berm at +8 ft NGVD and a wall crest elevation of +17.6 ft NGVD proved to be the most effective overall revetment configuration unless a cap is added to the seawall. This berm configuration appeared to be high enough and wide enough to dissipate wave energy well but still low enough so that the seawall provided an effective discontinuity to the wave and runup flow and allowed the recurve to function efficiently. To obtain the maximum effectiveness, the berm should have an elevation equal to the average annual high water event, be as wide as possible, and intersect the seawall low enough so that a major discontinuity to wave action and runup flow is maintained. By higher expected water levels a recurrence interval in the range of 1 to 5 years is implied. These findings appear to be consistent with recent research conducted at H.R.S. Wallingford on irregular wave overtopping of sea dikes (see Owen (1982) and Allsop*).

28. Increasing the height of the seawall is also a very effective method to reduce wave overtopping, although for many situations this option is not acceptable.

29. A new method to compute overtopping rates caused by irregular wave conditions has been presented which seems to have several advantages over the current method of computing irregular wave overtopping rates given in the SPM (1984). The method's advantages are that it:

- a. Is simple.
- b. Does not use the runup or potential runup to compute overtopping rates.
- c. Is naturally well adapted for use with irregular wave conditions.
- d. Provides a simple way to compare and rank the effectiveness of various structural configurations in reducing wave overtopping.

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* Personal communication with N. W. H. Allsop, Hydraulics Research Limited, Wallingford, Oxfordshire, England, 1985.

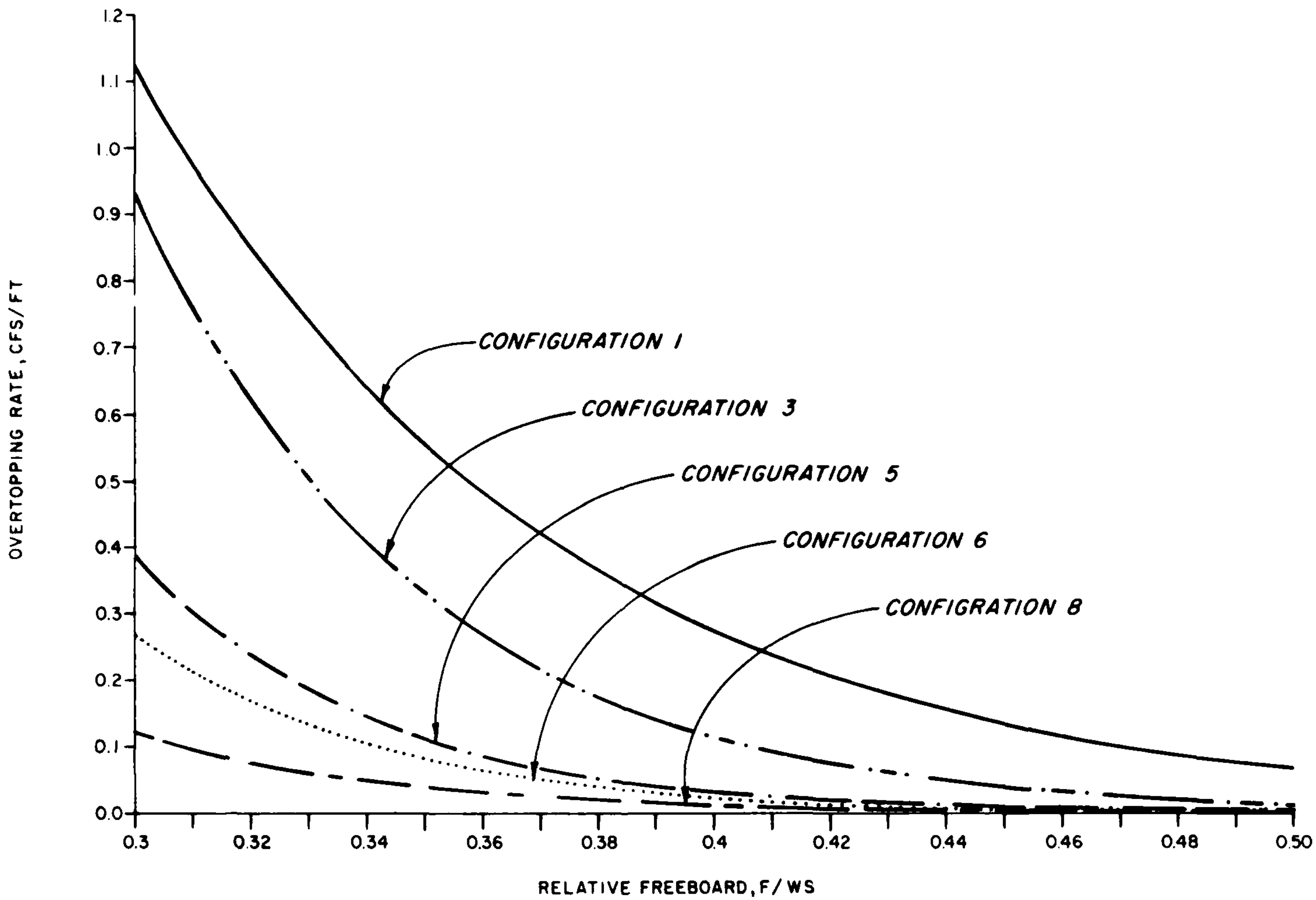

Figure 21. Comparison summary of data trends for Configurations 1, 3, 5, 6, and 8

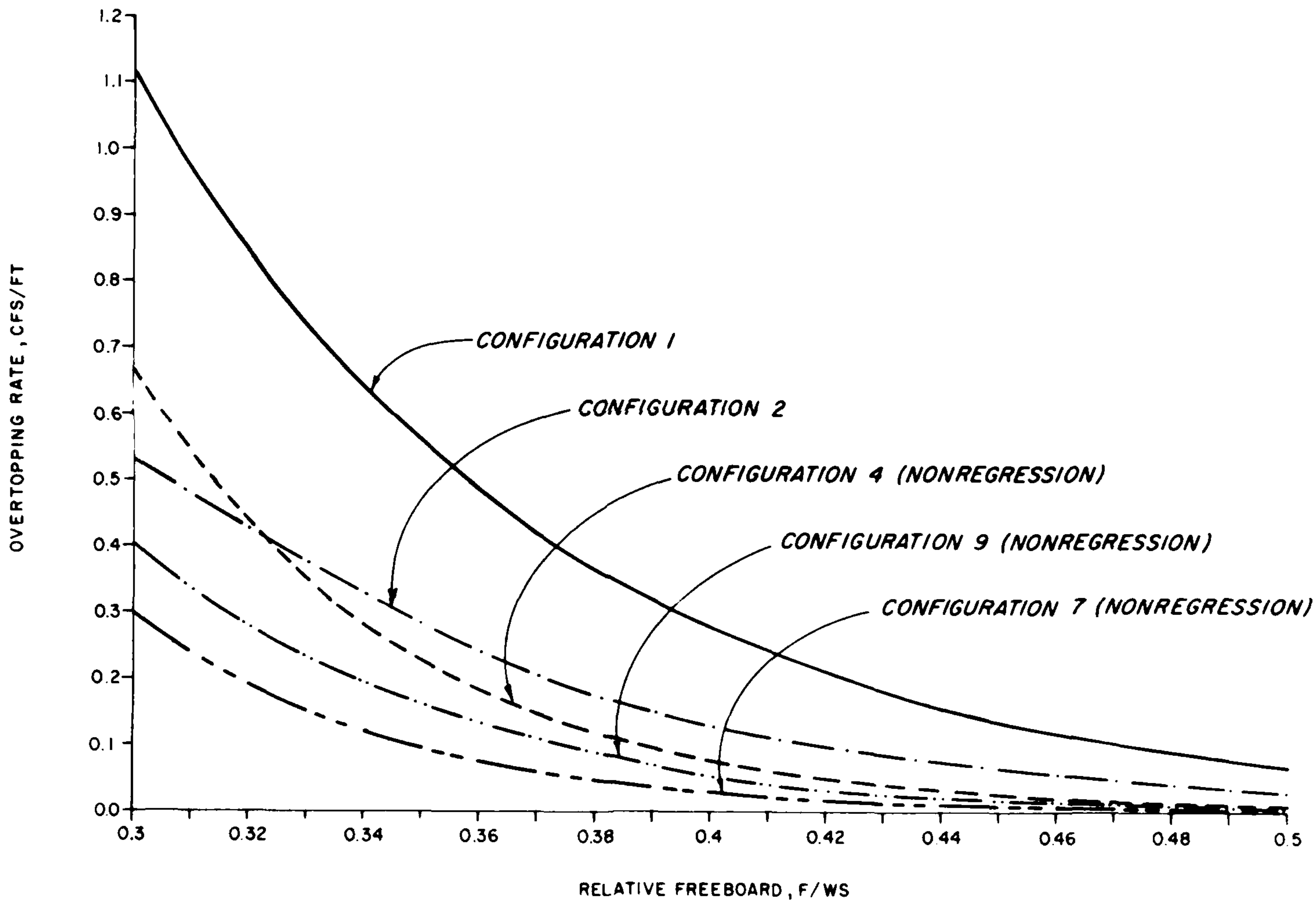

Figure 22. Comparison summary of data trends for Configurations 1, 2, 4, 7, and 9

It is also believed that this new method is more accurate than the SPM method because it was developed directly from irregular wave conditions rather than being adapted from monochromatic wave overtopping tests.

30. The new method of computing overtopping rates and overtopping data presented herein was used by Hardy and Crawford (in preparation) to compute the stage frequency curves for interior flooding at Roughans Point.

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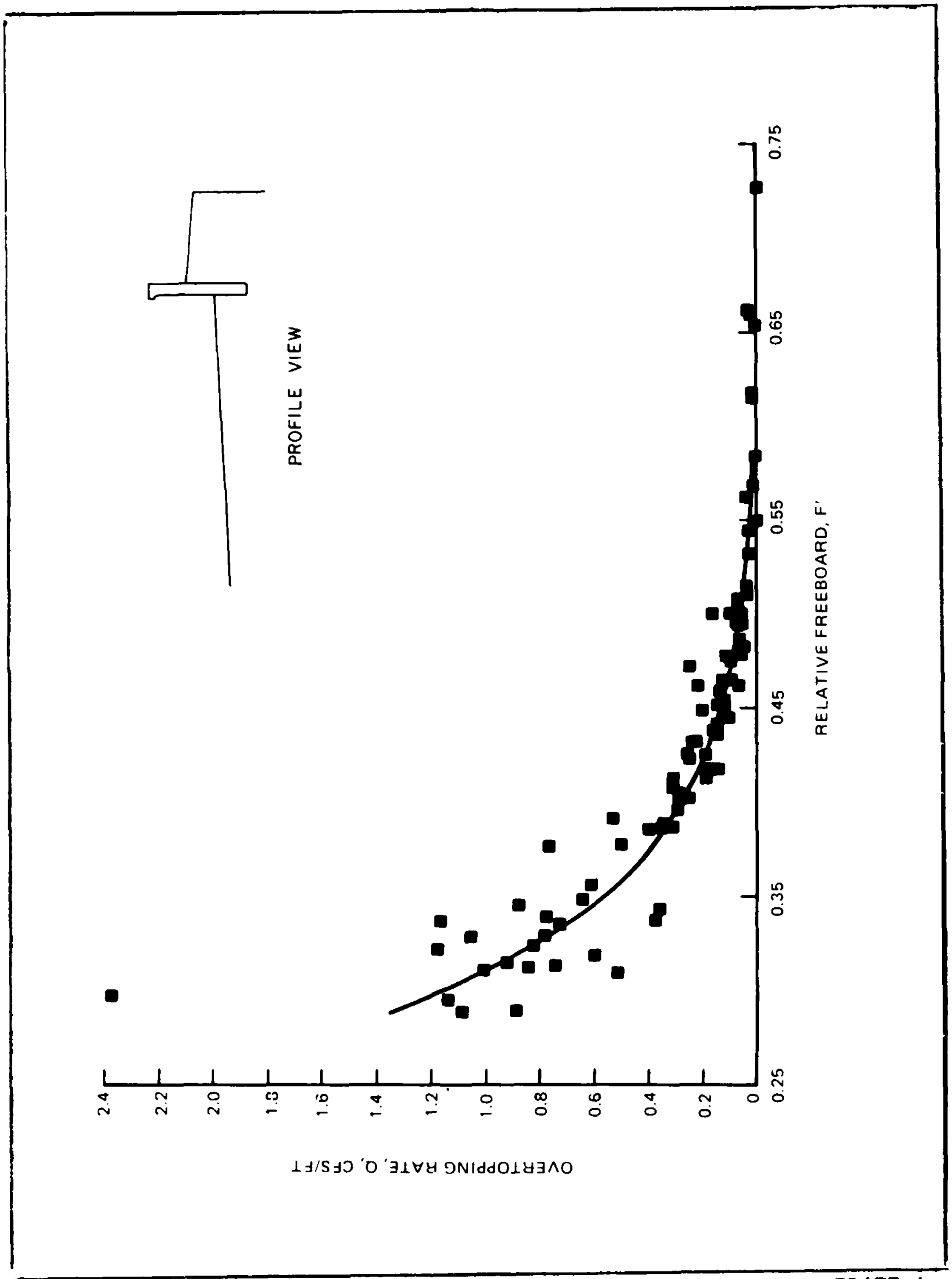

PROFILE VIEW
OVERTOPPING RATE, Q, CFS/FT
RELATIVE FREEBOARD, F'
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
0.25
0.35
0.45
0.55
0.65
0.75

PLATE 1

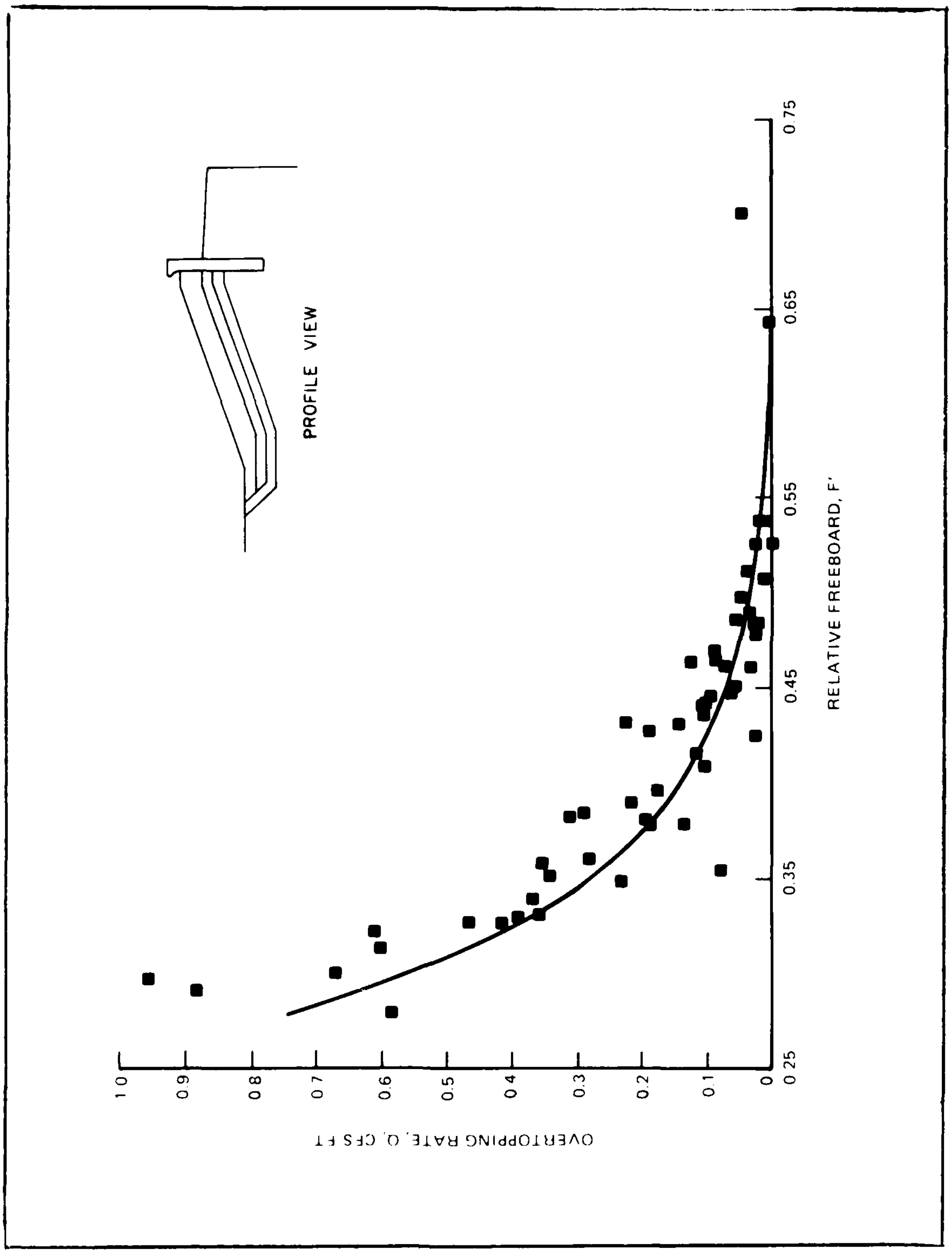

PROFILE VIEW
RELATIVE FREEBOARD, F'
0.25
0.35
0.45
0.55
0.65
0.75
OVERTOPPING RATE, Q, CFS FT
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

PLATE 2

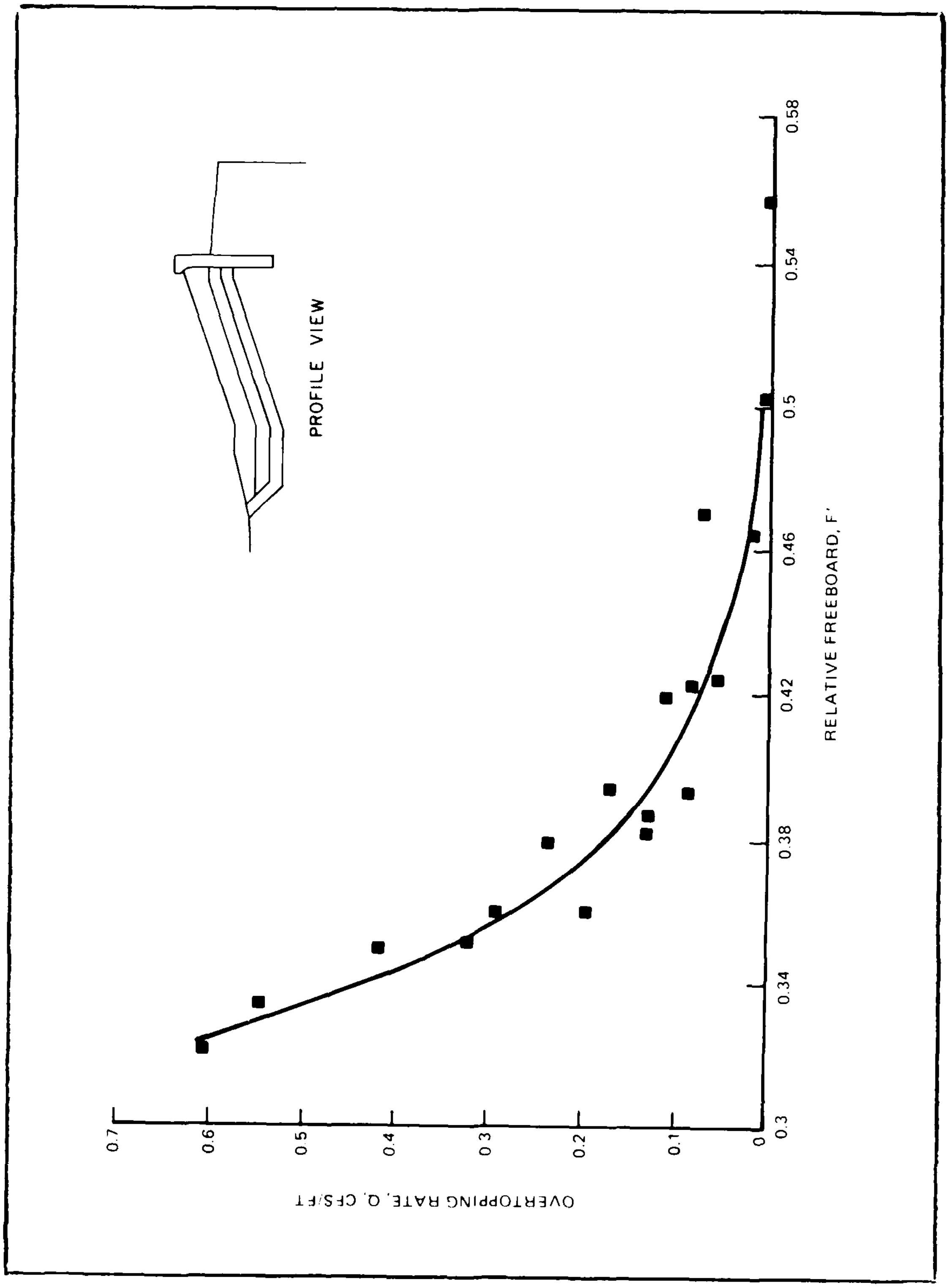
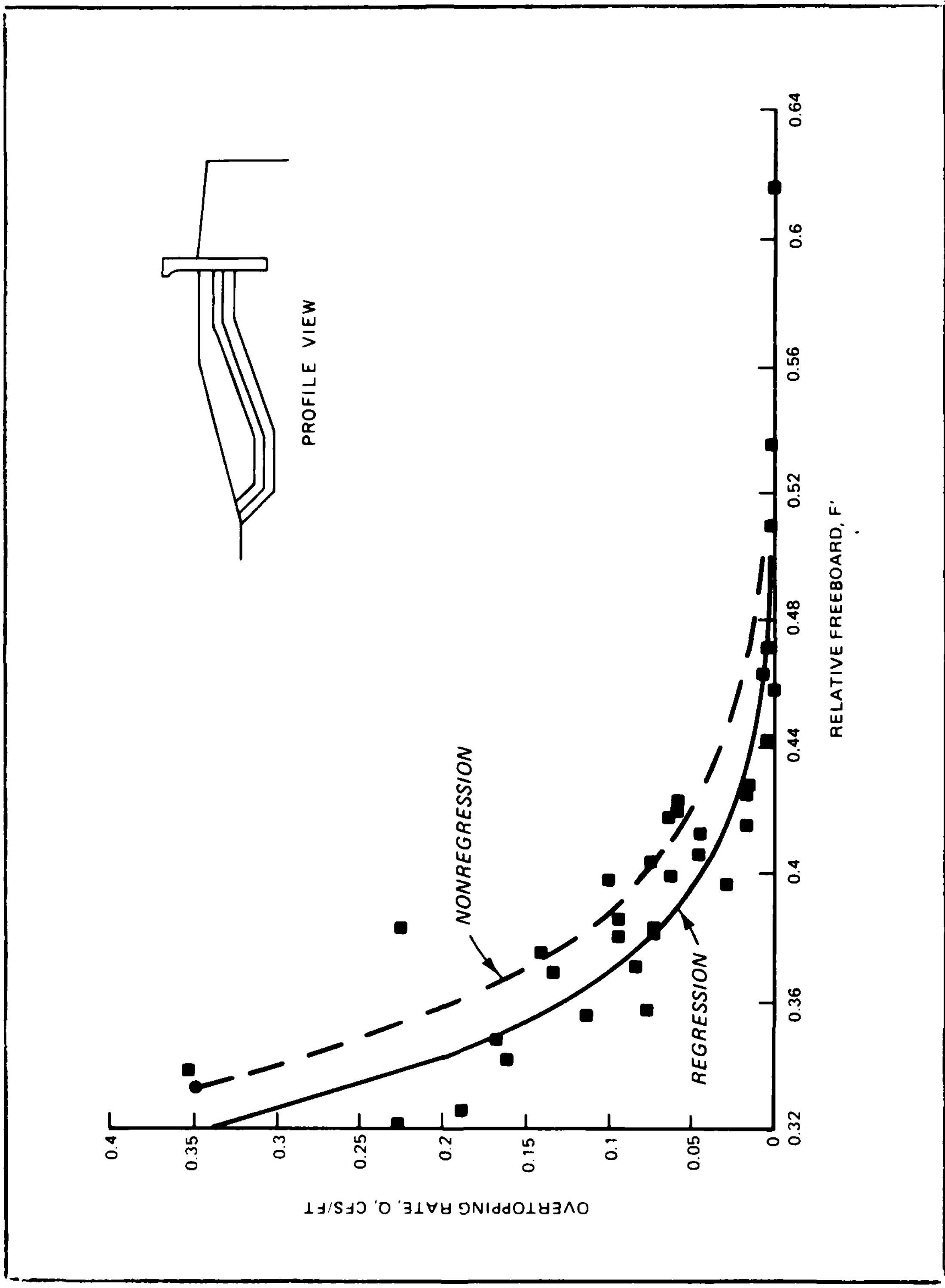

PROFILE VIEW
OVERTOPPING RATE, Q, CFS/FT
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
RELATIVE FREEBOARD, F'
0.3
0.34
0.38
0.42
0.46
0.5
0.54
0.58

PLATE 3



PROFILE VIEW
NONREGRESSION
REGRESSION
OVERTOPPING RATE, Q, CFS/FT
RELATIVE FREEBOARD, F'
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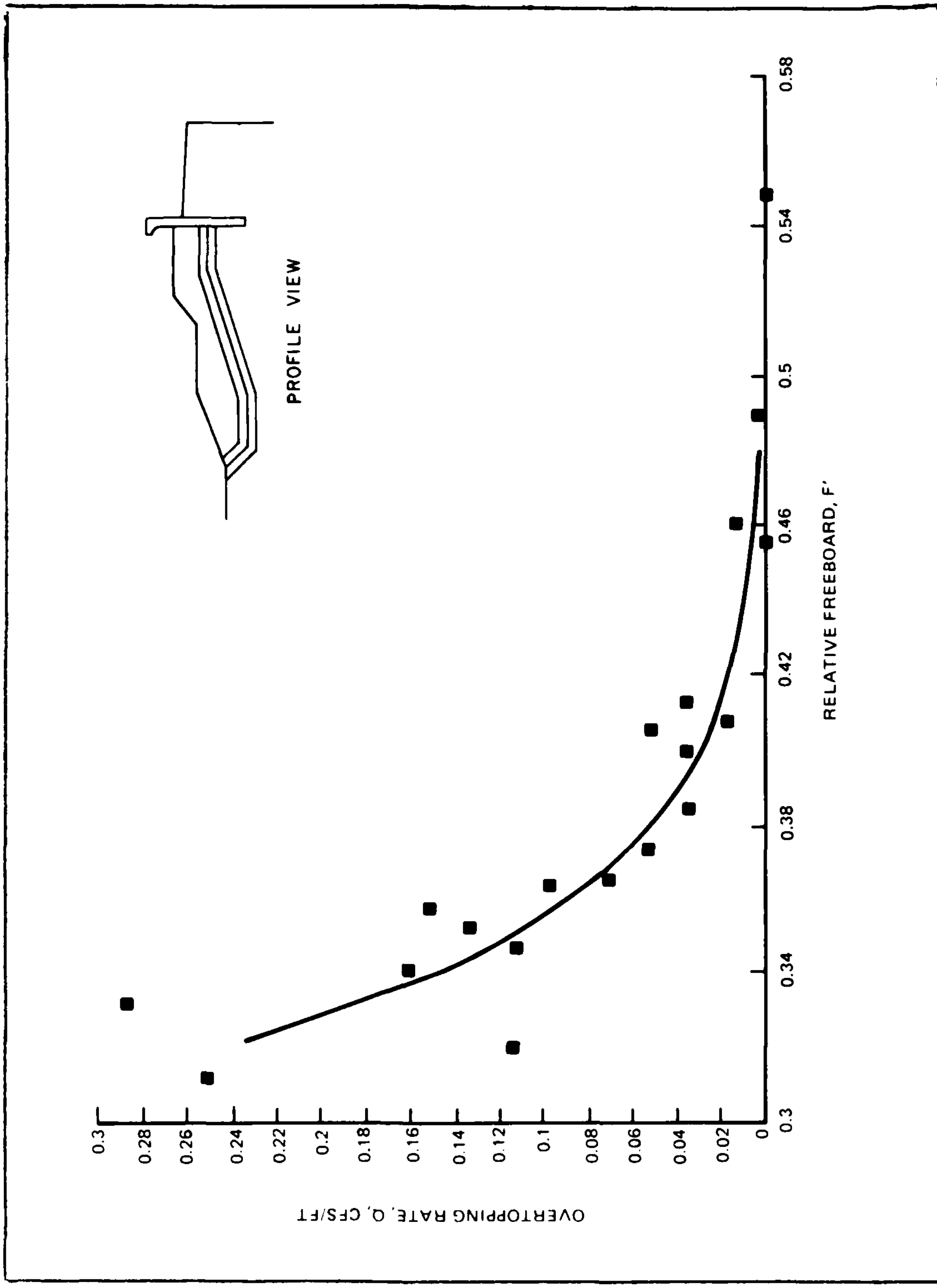
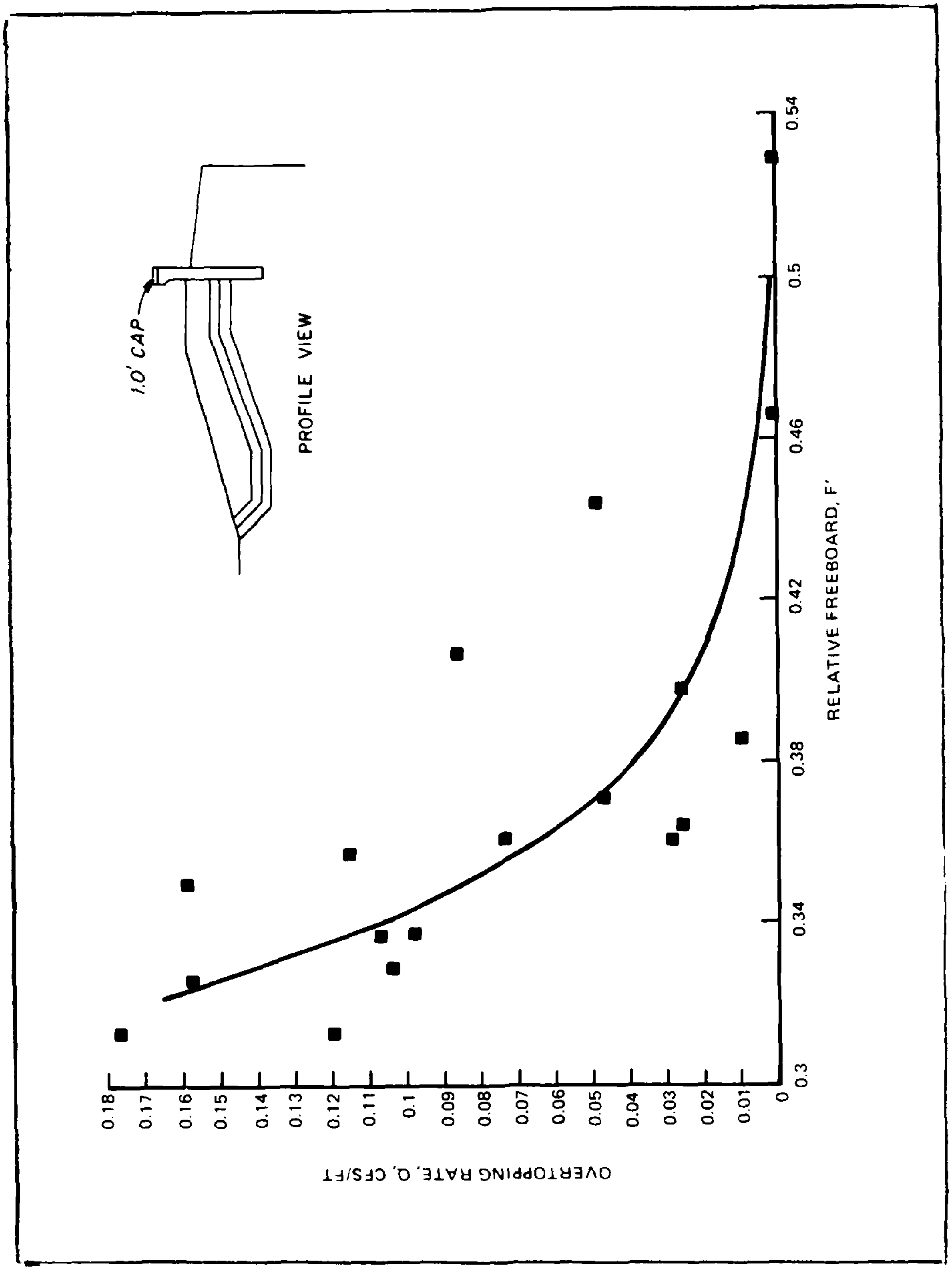
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.32
0.36
0.4
0.44
0.48
0.52
0.56
0.6
0.64

PLATE 4


PROFILE VIEW
RELATIVE FREEBOARD, F'
OVERTOPPING RATE, Q, CFS/FT
0.3
0.34
0.38
0.42
0.46
0.5
0.54
0.58
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3



1.0' CAP
PROFILE VIEW
OVERTOPPING RATE, Q, CFS/FT
RELATIVE FREEBOARD, F'
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.3
0.34
0.38
0.42
0.46
0.5
0.54

PLATE 6

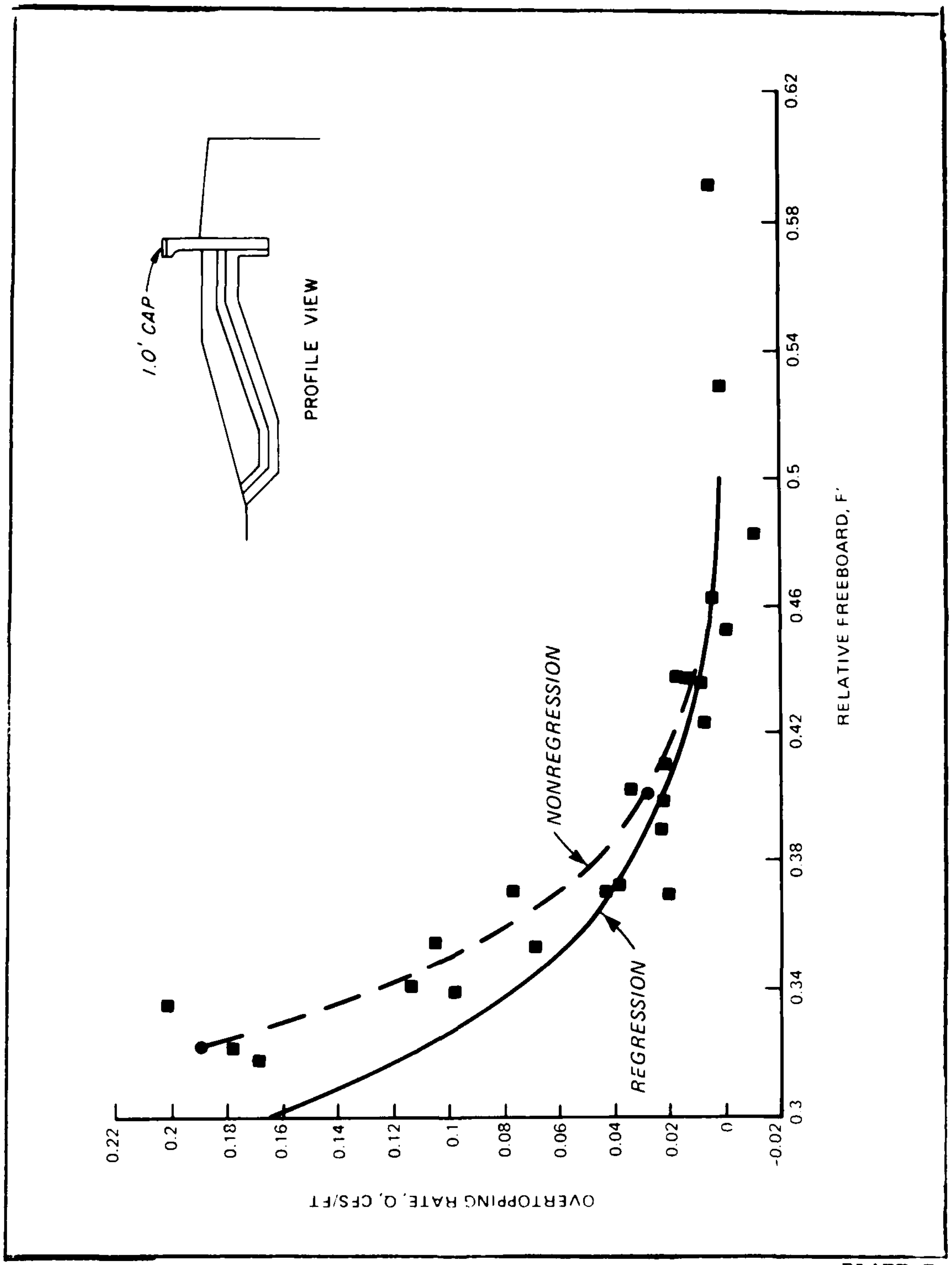
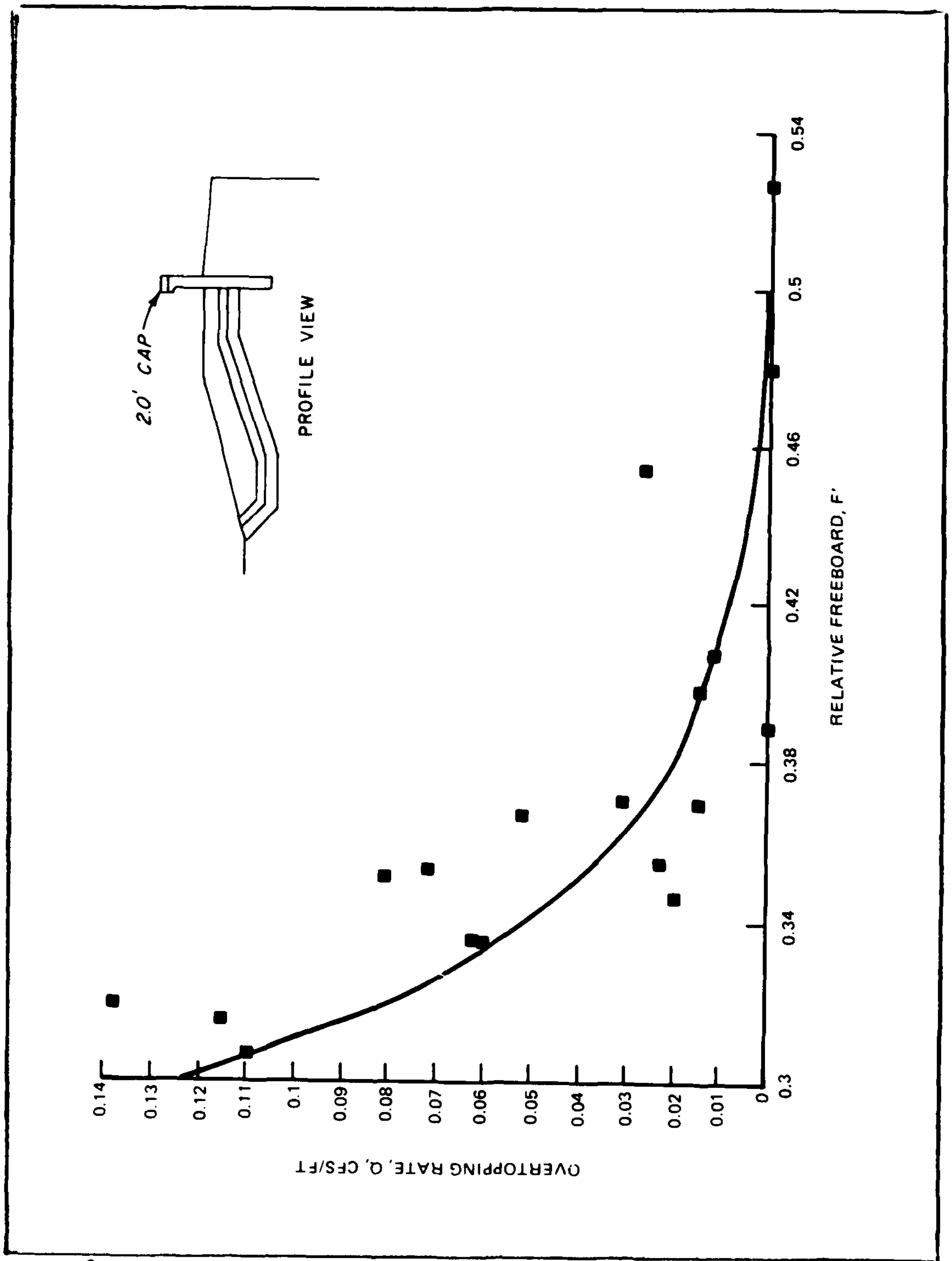

1.0' CAP
PROFILE VIEW
NONREGRESSION
REGRESSION
OVERTOPPING RATE, Q, CFS/FT
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
0.3
0.34
0.38
0.42
0.46
0.5
0.54
0.58
0.62
RELATIVE FREEBOARD, F'

PLATE 7



2.0' CAP
PROFILE VIEW
OVERTOPPING RATE, Q, CFS/FT
RELATIVE FREEBOARD, F'
0.3
0.34
0.38
0.42
0.46
0.5
0.54
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
0.14

PLATE 8

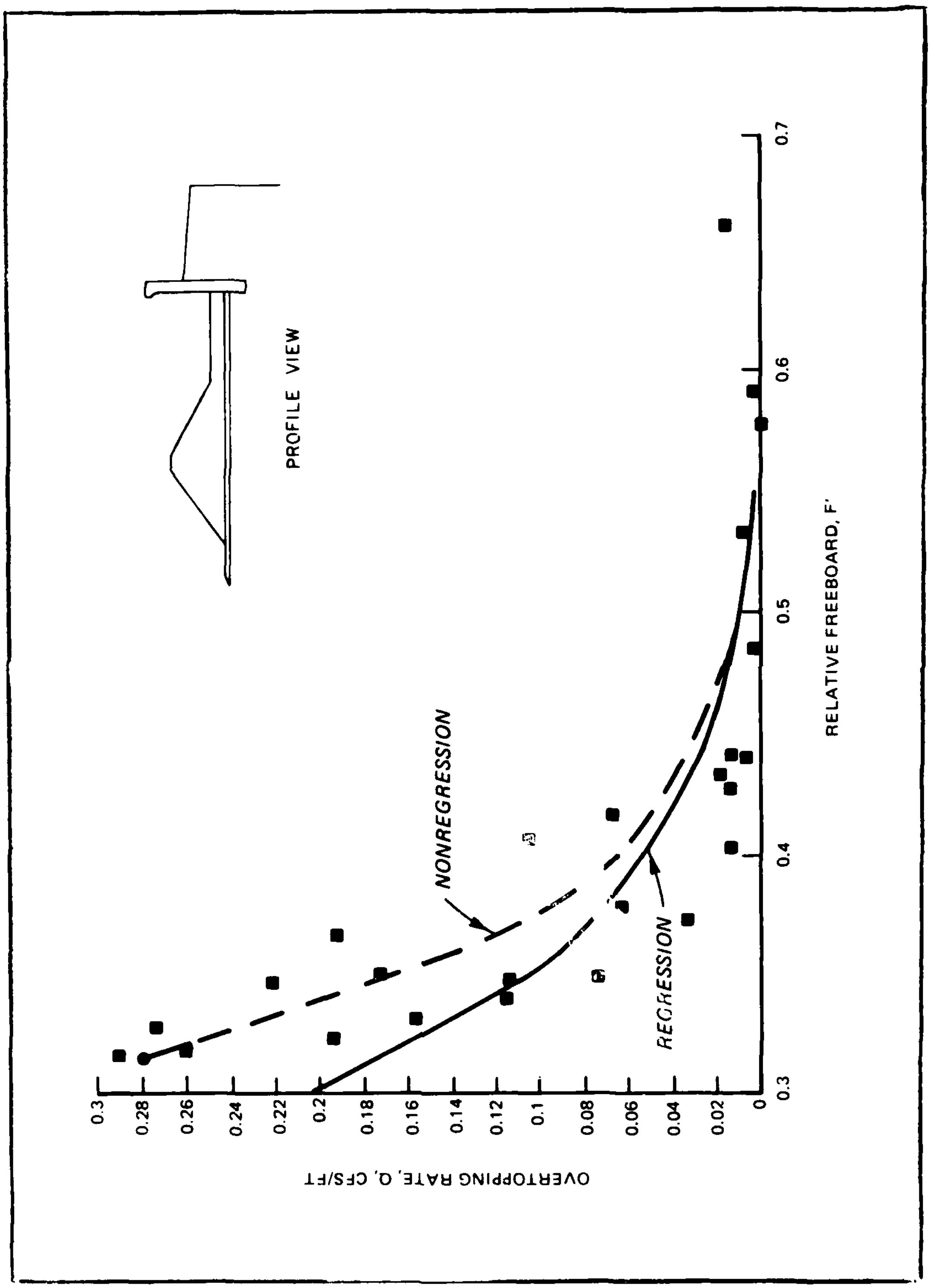
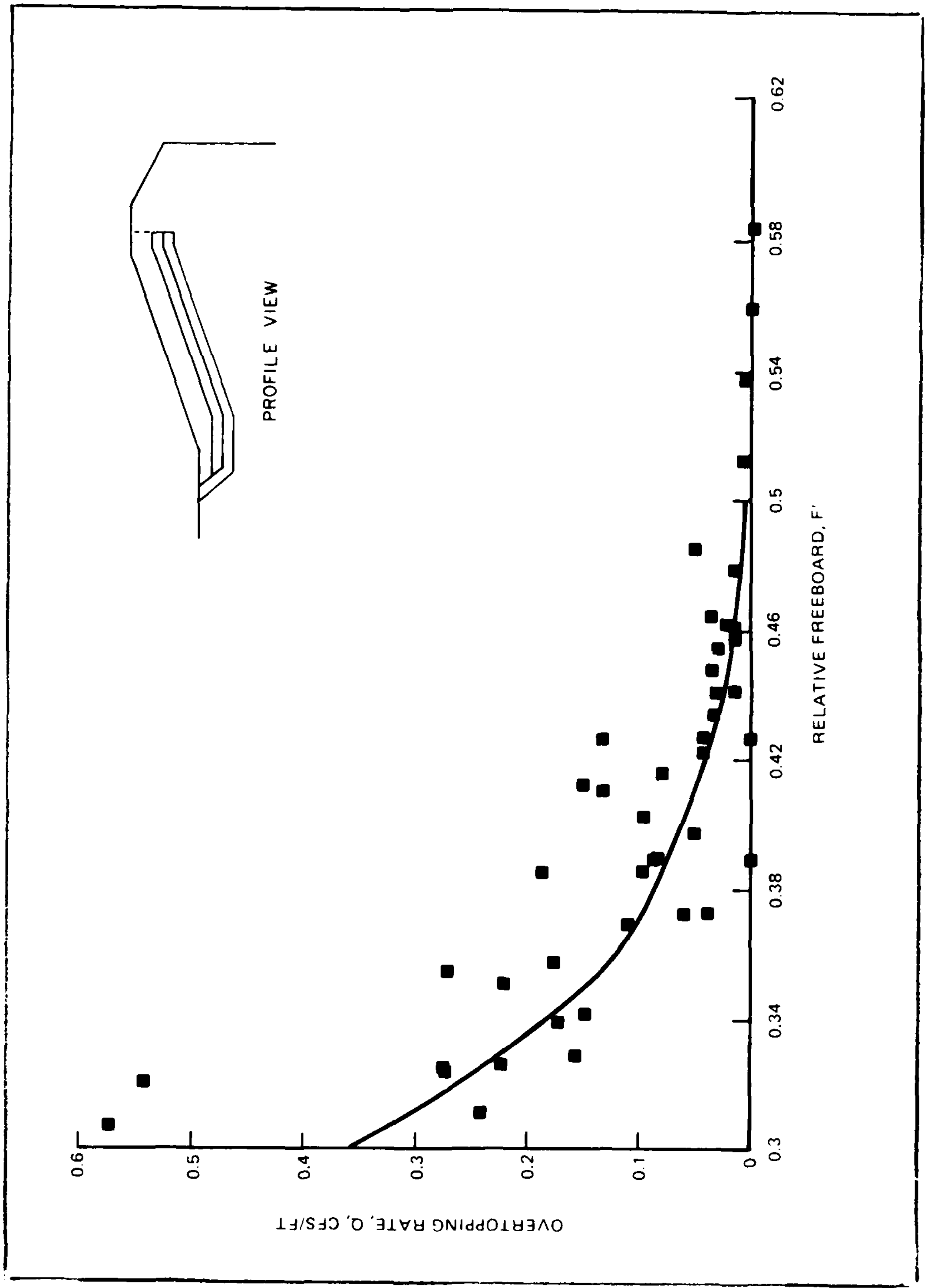

PROFILE VIEW
NONREGRESSION
REGRESSION
OVERTOPPING RATE, Q, CFS/FT
RELATIVE FREEBOARD, F'
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.3
0.4
0.5
0.6
0.7

PLATE 9


PROFILE VIEW
OVERTOPPING RATE, Q, CFS/FT
RELATIVE FREEBOARD, F'
0.6
0.5
0.4
0.3
0.2
0.1
0
0.3
0.34
0.38
0.42
0.46
0.5
0.54
0.58
0.62

APPENDIX A: DATA TABLES

Table A1

Seawall With No Revetment Data, Configuration 1

Test No.	Gage Seven Hmo ft.	Nom. Tp sec.	Gage Seven depth ft.	Nom. L ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Rel. Frbd. F/ws
1	5.55	8	12.464	154	2.031	2.027	9.136	8.944	0.327	0.341	0.033420	0.543734
2	6.8	8	12.456	154	2.031	2.026	9.144	8.936	0.341	0.383	0.100287	0.475287
3	6.97	8	12.52	154	2.031	2.034	9.08	9	0.383	0.431	0.114664	0.464255
4	7.15	8	12.472	154	2.034	2.025	9.128	8.952	0.431	0.486	0.131452	0.458843
5	5.79	9	12.472	175	2.031	2.028	9.128	8.952	0.486	0.514	0.066948	0.506108
6	6.79	9	12.44	175	2.031	2.024	9.16	8.92	0.514	0.573	0.141129	0.456705
7	7.22	9	12.464	175	2.031	2.027	9.136	8.944	0.573	0.64	0.160364	0.437238
8	7.82	9	12.424	175	2.031	2.022	9.176	8.904	0.64	0.72	0.191616	0.416392
9	4.09	10	12.496	195	2.031	2.031	9.104	8.976	0.729	0.734	0.011982	0.613863
10	4.08	10	12.488	195	2.031	2.03	9.112	8.968	0.734	0.74	0.014379	0.615406
11	5.76	10	12.408	195	2.031	2.02	9.192	8.888	0.74	0.77	0.071908	0.493306
12	6.76	10	12.448	195	2.031	2.025	9.152	8.928	0.77	0.83	0.143879	0.441441
13	7.21	10	12.416	195	2.031	2.021	9.184	8.896	0.83	0.91	0.191970	0.424355
14	7.44	10	12.4	195	2.031	2.019	9.2	8.88	0.91	0.97	0.144075	0.416288
15	5.88	7	12.472	133	2.031	2.028	9.128	8.952	0.97	0.971	0.002401	0.548917
16	6.58	7	12.448	133	2.031	2.025	9.152	8.928	0.97	0.987	0.040836	0.510600
17	6.92	7	12.416	133	2.031	2.021	9.184	8.896	0.987	1.01	0.055260	0.495462
18	7.29	7	12.408	133	2.031	2.02	9.192	8.888	1.01	1.033	0.055272	0.478969
19	6.21	7	12.424	133	2.031	2.022	9.176	8.904	1.033	1.047	0.033650	0.532077
20	6.31	8	12.448	154	2.031	2.025	9.152	8.928	1.06	1.085	0.060108	0.500022
21	6.35	9	12.448	175	2.031	2.025	9.152	8.928	1.081	1.131	0.120255	0.477149
22	6.51	10	12.432	195	2.031	2.023	9.168	8.912	1.131	1.18	0.117907	0.453463
23	7.93	9	12.424	175	2.031	2.022	9.176	8.904	1.179	1.257	0.187802	0.412532
24	4.84	7	13.224	137	2.078	2.075	8.376	9.704	0.102	0.109	0.016672	0.567849
25	6.24	7	13.176	137	2.078	2.069	8.424	9.656	0.109	0.129	0.047642	0.482119
26	6.6	7	13.168	137	2.078	2.068	8.432	9.648	0.129	0.168	0.092930	0.464866
27	6.76	7	13.152	137	2.078	2.066	8.448	9.632	0.168	0.228	0.143039	0.458369
28	4.56	8	13.248	158	2.078	2.078	8.352	9.728	0.228	0.244	0.038157	0.561817
29	6.05	8	13.144	158	2.078	2.065	8.456	9.624	0.244	0.348	0.248171	0.471095
30	6.49	8	13.176	158	2.078	2.069	8.424	9.656	0.348	0.396	0.114625	0.447853
31	6.87	8	13.16	158	2.078	2.067	8.44	9.64	0.396	0.489	0.222239	0.432001
32	4.95	9	13.168	180	2.078	2.068	8.432	9.648	0.489	0.505	0.038255	0.514165
33	6.08	9	13.16	180	2.078	2.067	8.44	9.64	0.505	0.591	0.205723	0.448727
34	7.16	9	13.072	180	2.078	2.056	8.528	9.552	0.591	0.723	0.316096	0.406581
35	7.4	9	13.096	180	2.078	2.059	8.504	9.576	0.739	0.863	0.297354	0.396623
36	4.96	10	13.152	201	2.078	2.066	8.448	9.632	0.863	0.896	0.079194	0.495869
37	6.23	10	13.176	201	2.078	2.069	8.424	9.656	0.896	0.989	0.223322	0.424744
38	7.13	10	13.024	201	2.078	-2.05	8.576	9.504	0.989	1.109	0.288455	0.395208
39	7.33	10	13.088	201	2.078	2.058	8.512	9.568	1.109	1.256	0.353814	0.385091
40	6.91	10	13.072	201	2.078	2.056	8.528	9.552	1.256	1.359	0.248210	0.401294
41	6.54	9	13.088	180	2.078	2.058	8.512	9.568	1.359	1.458	0.238803	0.431077
42	6.44	8	13.16	158	2.078	2.067	8.44	9.64	1.458	1.519	0.147255	0.451023
43	7.03	8	13.176	158	2.078	2.069	8.424	9.656	1.519	1.625	0.256092	0.424615
44	7.68	9	13.08	180	2.078	2.057	8.52	9.56	1.625	1.767	0.343476	0.387651
45	6.15	12	13.16	243	2.078	2.067	8.44	9.64	0.012	0.135	0.292873	0.402924
46	6.56	12	13.16	243	2.078	2.067	8.44	9.64	0.135	0.267	0.314695	0.385955
47	4.82	7	13.728	140	2.125	2.091	7.872	10.208	0.267	0.281	0.033400	0.531305
48	6.22	7	13.792	140	2.125	2.099	7.808	10.272	0.281	0.323	0.100229	0.444600
49	6.73	7	13.792	140	2.125	2.099	7.808	10.272	0.323	0.429	0.253141	0.421845
50	7.5	7	14.112	140	2.125	2.139	7.488	10.592	0.429	0.638	0.499885	0.376370

(Continued)

Table A1 (Concluded)

Test No.	Gage Seven Hmo ft.	Nom. Tp sec.	Gage Seven depth ft.	Nom. L ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Rel. Frbd. F/ws
51	4.74	8	13.912	162	2.139	2.1	7.688	10.392	0.638	0.679	0.098182	0.499792
52	6.24	8	13.992	162	2.125	2.124	7.608	10.472	0.679	0.809	0.311570	0.411758
53	7.85	8	14.4	162	2.125	2.175	7.2	10.88	0.809	1.294	1.165867	0.334385
54	7.55	8	14.296	162	2.175	2.112	7.304	10.776	1.294	1.56	0.641749	0.348143
55	5.1	9	13.832	184	2.125	2.104	7.768	10.312	1.56	1.649	0.215088	0.460952
56	6.47	9	14.2	184	2.125	2.15	7.4	10.68	0.029	0.35	0.765196	0.374705
57	7.69	9	14.36	184	2.15	2.145	7.24	10.84	0.35	0.791	1.055161	0.326724
58	7.95	9	14.36	184	2.145	2.15	7.24	10.84	0.791	1.28	1.175301	0.319561
59	5.01	10	14.392	206	2.15	2.149	7.208	10.872	0.21	0.28	0.166955	0.416837
60	6.55	10	14.264	206	2.149	2.134	7.336	10.744	0.28	0.535	0.609160	0.354821
61	7.4	10	14.096	206	2.134	2.128	7.504	10.576	0.535	0.84	0.730590	0.334592
62	8.21	10	13.952	206	2.125	2.119	7.648	10.432	0.039	0.289	0.595798	0.318197
63	6.97	12	13.728	250	2.125	2.091	7.872	10.208	0.289	0.44	0.360567	0.342465
64	6.98	12	14.176	250	2.125	2.147	7.424	10.656	0.44	0.784	0.823406	0.322666
65	3.84	7	14.176	140	2.147	2.125	7.424	10.656	0.784	0.787	0.007192	0.583052
66	2.68	8	13.96	162	2.125	2.12	7.64	10.44	0.787	0.788	0.002397	0.726382
67	6.84	8	13.928	162	2.125	2.116	7.672	10.408	0.788	1.011	0.535269	0.390570
68	2.86	9	14.016	184	2.125	2.127	7.584	10.496	1.011	1.025	0.033643	0.661782
69	NA	9	14.04	184	2.127	2.128	7.56	10.52	1.025	1.337	0.750941	NA
70	2.7	10	14.04	206	2.128	2.127	7.56	10.52	0.448	0.457	0.021509	0.660171
71	7.6	10	13.896	206	2.125	2.112	7.704	10.376	0.457	0.78	0.773188	0.337456
72	2.51	12	14	250	2.125	2.125	7.6	10.48	0.78	0.78	0	0.653207
73	8.05	9	13.744	184	2.125	2.093	7.856	10.224	0.78	1.146	0.879055	0.343873
74	4.44	7	14.736	143	2.172	2.17	6.864	11.216	0.011	0.039	0.066638	0.485895
75	8.11	7	14.496	143	2.172	2.14	7.104	10.976	0.039	0.197	0.376375	0.336545
76	7.57	8	14.648	166	2.172	2.159	6.952	11.128	0.197	0.526	0.785583	0.328102
77	8.55	8	14.496	166	2.172	2.14	7.104	10.976	0.526	0.946	1.006533	0.309140
78	8.82	7	15.056	143	2.172	2.21	6.544	11.536	0.946	1.931	2.376665	0.293147
79	4.01	8	14.672	166	2.172	2.162	6.928	11.152	0.441	0.51	0.164940	0.499431
80	4.55	9	14.744	189	2.172	2.171	6.856	11.224	0.51	0.568	0.138731	0.435086
81	7.83	9	14.504	189	2.172	2.141	7.096	10.984	0.025	0.411	0.920398	0.313582
82	9.05	9	14.288	189	2.172	2.114	7.312	10.768	0.411	0.886	1.137374	0.293393
83	4.23	10	14.416	211	2.172	2.13	7.184	10.896	0.886	0.913	0.064808	0.461365
84	7.86	10	14.248	211	2.172	2.109	7.352	10.728	0.016	0.328	0.743615	0.312389
85	8.59	10	14.424	211	2.172	2.131	7.176	10.904	0.328	0.783	1.088499	0.287381
86	7	12	14.416	256	2.172	2.13	7.184	10.896	0.571	0.786	0.514961	0.309186
87	7.83	12	14.392	256	2.172	2.127	7.208	10.872	0.206	0.578	0.888522	0.287890
88	3.93	5	14.56	96	2.172	2.148	7.04	11.04	0.578	0.583	0.011964	0.617381
89	6.9	5	15.224	96	2.172	2.231	6.376	11.704	0.583	0.75	0.399946	0.384201
90	8.38	7	14.883	143	2.231	2.13	6.712	11.368	0.176	0.529	0.842816	0.311107

Table A2

Standard Revetment Seawall Data, Configuration 2

Test No.	Gage Seven Hmo ft.	Nom. Tp sec.	Gage Seven Depth ft.	Nom. Lp Gage Seven ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe Depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Relative Frbd. F/ws
92	3.78	8	12.488	154	2.021	2.04	9.112	8.968	0.064	0.099	0.046302	0.700666
93	7.53	8	12.408	153	2.04	2.011	9.192	8.888	0.099	0.146	0.062202	0.446888
94	7.81	8	12.336	153	2.021	2.021	9.264	8.816	0.146	0.227	0.107267	0.439950
95	6.43	7	12.336	132	2.021	2.021	9.264	8.816	0.227	0.227	0	0.525824
96	7.55	7	12.248	132	2.021	2.01	9.352	8.728	0.227	0.246	0.025173	0.477439
97	7.35	7	12.264	132	2.021	2.012	9.336	8.744	0.246	0.288	0.055663	0.485135
98	6.01	9	12.184	173	2.012	2.011	9.416	8.664	0.288	0.318	0.039773	0.511551
99	6.96	9	12.168	173	2.021	2	9.432	8.648	0.318	0.381	0.083562	0.464757
100	8.12	9	12.256	173	2.021	2.011	9.344	8.736	0.381	0.468	0.115480	0.414967
101	6.01	10	12.336	194	2.021	2.021	9.264	8.816	0.468	0.486	0.023904	0.484014
102	6.52	10	12.288	194	2.021	2.015	9.312	8.768	0.517	0.571	0.071761	0.461093
103	7.29	10	12.248	193	2.021	2.01	9.352	8.728	0.571	0.679	0.143635	0.430085
104	5.78	5	12.336	90	2.021	2.021	9.264	8.816	0.679	0.682	0.003992	0.643019
105	4.74	12	12.256	234	2.021	2.011	9.344	8.736	0.682	0.697	0.019961	0.537347
106	5.8	12	12.256	234	2.021	2.011	9.344	8.736	0.697	0.762	0.086535	0.469701
107	6.5	12	12.336	235	2.021	2.021	9.264	8.816	0.762	0.93	0.223913	0.431164
108	7.3	8	12.328	153	2.021	2.02	9.272	8.808	0.035	0.059	0.031739	0.460653
109	6.14	7	12.408	133	2.031	2.02	9.192	8.888	0.251	0.255	0.005300	0.537573
110	7.21	7	12.408	133	2.031	2.02	9.192	8.888	0.255	0.278	0.030482	0.482977
111	6.21	8	12.416	154	2.031	2.021	9.184	8.896	0.279	0.288	0.013255	0.507669
112	7.56	8	12.408	153	2.031	2.02	9.192	8.888	0.288	0.359	0.094150	0.445705
113	6.11	9	12.48	175	2.031	2.029	9.12	8.96	0.359	0.387	0.037147	0.488216
114	8.21	9	12.336	174	2.031	2.011	9.264	8.816	0.387	0.466	0.104863	0.408007
115	5.5	7	13.176	136	2.078	2.069	8.424	9.656	0.466	0.486	0.026560	0.525482
116	7.09	7	13.208	136	2.078	2.073	8.392	9.688	0.486	0.56	0.098319	0.441901
117	5.57	8	13.152	158	2.078	2.066	8.448	9.632	0.56	0.597	0.049186	0.497709
118	7.12	8	13.08	157	2.078	2.057	8.52	9.56	0.597	0.738	0.187601	0.426521
119	5.82	9	13.16	179	2.078	2.067	8.44	9.64	0.738	0.832	0.125210	0.462862
120	7.86	9	13.096	179	2.078	2.059	8.504	9.576	0.832	1.064	0.309519	0.381998
121	6.03	10	13.16	200	2.078	2.067	8.44	9.64	0.624	0.702	0.103775	0.435519
122	7.45	10	13.056	199	2.078	2.054	8.544	9.536	0.702	0.917	0.286453	0.383392
123	6.05	7	13.848	139	2.125	2.106	7.752	10.328	0.21	0.252	0.055644	0.450491
124	7.61	7	13.808	139	2.125	2.101	7.792	10.288	0.252	0.414	0.214841	0.388764
125	5.71	8	13.928	162	2.125	2.116	7.672	10.408	0.414	0.49	0.100906	0.440722
126	8.54	8	13.896	162	2.125	2.112	7.704	10.376	0.49	0.765	0.365747	0.338513
127	6.42	9	13.84	183	2.125	2.105	7.76	10.32	0.749	0.881	0.175878	0.395521
128	8.43	9	13.872	183	2.125	2.109	7.728	10.352	0.881	1.172	0.388528	0.328366
129	6.4	10	13.92	206	2.125	2.115	7.68	10.4	0.507	0.647	0.186107	0.377527
130	8.11	10	13.96	206	2.125	2.12	7.64	10.44	0.647	1.104	0.609271	0.320571
131	6.53	7	14.688	143	2.172	2.164	6.912	11.168	1.121	1.22	0.132364	0.378484
132	7.68	7	14.536	142	2.172	2.145	7.064	11.016	0.619	0.791	0.228930	0.347684
133	8.11	7	14.24	141	2.172	2.108	7.36	10.72	0.791	1.046	0.340107	0.350379
134	5.06	8	14.672	166	2.172	2.162	6.928	11.152	1.046	1.191	0.193769	0.379516
135	7.63	8	14.672	166	2.172	2.162	6.928	11.152	0.131	0.444	0.414911	0.325483
136	8.31	8	14.208	163	2.172	2.104	7.392	10.688	0.444	0.712	0.356265	0.329661
137	6.89	9	14.184	185	2.172	2.101	7.416	10.664	0.712	0.922	0.279812	0.359230
138	7.81	9	14.288	186	2.172	2.114	7.312	10.768	0.922	1.272	0.467621	0.325433
139	9.17	9	14.256	186	2.172	2.11	7.344	10.736	0.581	1.298	0.956495	0.293785
140	6.29	10	NA	NA	2.172	NA	NA	NA	0.797	NA	NA	NA
141	7.76	10	14.36	209	2.172	2.123	7.24	10.84	0.065	0.518	0.600517	0.311471

(Continued)

Table A2 (Concluded)

Test No.	Gage Seven Hmo ft.	Nom. Tp sec.	Gage Seven Depth ft.	Mon. Lp Gage Seven ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe Depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Relative Frbd. F/Hs
142	9.09	10	14.176	207	2.172	2.1	7.424	10.656	0.518	1.181	0.833686	0.288001
143	5.35	12	14.664	255	2.172	2.161	6.936	11.144	0.13	0.397	0.353850	0.357518
144	6.9	12	14.752	256	2.174	2.17	6.848	11.232	0.397	0.9	0.669121	0.297628
145	7.71	12	14.744	256	2.172	2.171	6.856	11.224	0.607	1.046	0.584995	0.276746
146	6.98	5	14.52	95	2.172	2.143	7.08	11	0.247	0.266	0.025178	0.424612
147	6.49	10	14.296	208	2.172	2.115	7.304	10.776	0.266	0.325	0.078216	0.354233

Table A3

Absorber/Revetment Seawall

Data, Configuration 3

Test No.	Gage Seven Hmo ft.	Nom. Tp sec.	Gage Seven depth ft.	Nom. Lp ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Rel. Frbd. F/Hs
1	5.55	8	14.36	164.05	2.15	2.145	7.24	10.84	0.061	0.125	0.085	0.422
2	6.59	8	14.32	163.84	2.15	2.14	7.28	10.8	0.125	0.304	0.237	0.379
3	7.32	8	14.2	163.22	2.15	2.125	7.4	10.68	0.304	0.524	0.292	0.359
4	4.81	5	14.36	94.77	2.15	2.145	7.24	10.84	0.524	0.528	0.005	0.557
5	5.61	5	14.368	94.79	2.15	2.146	7.232	10.848	0.528	0.533	0.007	0.502
6	6.39	5	14.312	94.65	2.15	2.139	7.288	10.792	0.533	0.549	0.021	0.464
7	6.09	7	14.24	140.92	2.15	2.13	7.36	10.72	0.549	0.591	0.056	0.424
8	6.96	7	14.264	141.03	2.15	2.133	7.336	10.744	0.591	0.688	0.129	0.387
9	7.68	7	14.312	141.23	2.15	2.139	7.288	10.792	0.688	0.835	0.196	0.360
10	6.05	9	14.16	185.19	2.15	2.12	7.44	10.64	0.855	0.984	0.172	0.393
11	7.2	9	14.16	185.19	2.15	2.12	7.44	10.64	0.984	1.225	0.322	0.350
12	8.03	9	14.32	186.15	2.15	2.14	7.28	10.8	1.225	1.678	0.607	0.318
13	5.97	10	14.168	207.25	2.15	2.121	7.432	10.648	0.045	0.35	0.404	0.382
14	6.82	10	14.2	207.47	2.15	2.125	7.4	10.68	0.35	0.665	0.418	0.348
15	7.39	10	14.16	207.19	2.15	2.12	7.44	10.64	0.665	1.075	0.547	0.331
16	5.72	8	13.456	159.28	2.1	2.082	8.144	9.936	1.075	1.13	0.073	0.470
17	6.86	8	13.408	159.02	2.1	2.076	8.192	9.888	1.13	1.214	0.112	0.419
18	6.71	8	13.984	162.09	2.1	2.148	7.616	10.464	1.214	2.179	1.297	0.393

Table A4

Riprap with Wide Berm Data, Configuration 4

Test No.	Gage Seven Hmo ft.	Nom. Tp sec.	Gage Seven depth ft.	Nom. L ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Rel. Frbd. F/ws
19	6.000	8	14.160	163.01	2.15	2.120	7.440	10.640	0.587	0.620	0.044	0.412
20	5.840	8	14.160	163.01	2.15	2.120	7.440	10.640	0.620	0.664	0.059	0.420
21	6.013	8	14.296	163.72	2.15	2.137	7.304	10.776	0.664	0.720	0.075	0.404
22	5.079	5	14.392	94.84	2.15	2.149	7.208	10.872	0.720	0.721	0.001	0.535
23	6.048	5	14.456	95.00	2.15	2.157	7.144	10.936	0.721	0.724	0.004	0.472
24	6.752	5	14.392	94.84	2.15	2.149	7.208	10.872	0.724	0.727	0.004	0.442
25	6.630	7	14.312	141.23	2.15	2.139	7.288	10.792	0.727	0.749	0.029	0.397
26	7.244	7	14.376	141.51	2.15	2.147	7.224	10.856	0.749	0.812	0.084	0.370
27	7.856	7	14.296	141.16	2.15	2.137	7.304	10.776	0.812	0.897	0.113	0.355
28	6.233	9	14.240	185.67	2.15	2.130	7.360	10.720	0.980	1.149	0.226	0.381
29	6.999	9	14.160	185.19	2.15	2.120	7.440	10.640	1.149	1.207	0.078	0.357
30	8.128	9	14.200	185.43	2.15	2.125	7.400	10.680	0.289	0.460	0.227	0.321
31	5.927	10	14.240	207.74	2.15	2.130	7.360	10.720	0.460	0.531	0.094	0.379
32	6.989	10	14.240	207.74	2.15	2.130	7.360	10.720	0.531	0.652	0.161	0.340
33	7.732	10	14.104	206.81	2.15	2.113	7.496	10.584	0.652	0.793	0.188	0.324
34	4.769	12	14.176	251.00	2.15	2.122	7.424	10.656	0.793	0.806	0.017	0.415
35	6.070	12	14.320	252.22	2.15	2.140	7.280	10.800	0.806	0.931	0.167	0.346
36	6.759	12	14.048	249.91	2.15	2.106	7.552	10.528	0.931	1.196	0.354	0.335
37	6.521	8	13.576	159.92	2.10	2.097	8.024	10.056	0.235	0.279	0.058	0.424
39	7.191	8	13.568	159.88	2.10	2.096	8.032	10.048	0.323	0.399	0.101	0.397
40	4.873	5	13.576	92.82	2.10	2.097	8.024	10.056	0.399	0.400	0.001	0.617
41	5.989	5	13.600	92.88	2.10	2.100	8.000	10.080	0.400	0.401	0.001	0.536
42	6.456	5	13.600	92.88	2.10	2.100	8.000	10.080	0.401	0.402	0.001	0.509
43	6.106	7	13.600	138.11	2.10	2.100	8.000	10.020	0.402	0.407	0.007	0.463
44	6.939	7	13.600	138.11	2.10	2.100	8.000	10.080	0.407	0.420	0.017	0.425
45	7.460	7	13.584	138.04	2.10	2.098	8.016	10.064	0.420	0.454	0.045	0.406
46	6.315	9	13.528	181.30	2.10	2.091	8.072	10.008	0.454	0.502	0.064	0.417
47	7.116	9	13.544	181.40	2.10	2.093	8.056	10.024	0.502	0.573	0.094	0.335
48	7.764	9	13.448	180.80	2.10	2.081	8.152	9.928	0.573	0.673	0.133	0.369
49	5.713	10	13.560	203.01	2.10	2.095	8.040	10.040	0.673	0.685	0.016	0.428
50	6.800	10	13.528	202.78	2.10	2.091	8.072	10.008	0.685	0.740	0.073	0.383
51	6.819	10	13.552	202.95	2.10	2.094	8.048	10.032	0.740	0.795	0.073	0.381
52	4.660	12	13.599	246.05	2.10	2.100	8.001	10.079	0.795	0.795	.000	0.458
53	5.764	12	13.560	245.71	2.10	2.095	8.040	10.040	0.795	0.842	0.063	0.399
54	6.316	12	13.592	245.99	2.10	2.099	8.008	10.072	0.842	0.948	0.141	0.374

Table A5

Riprap with Two Berms Data, Configuration 5

Test No.	Gage Seven Hmo ft.	Nom. Tp sec.	Gage Seven depth ft.	Nom. L ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Rel. Frbd. F/ws
55	5.964	8	14.399	164.25	2.15	2.150	7.201	10.879	0.200	0.227	0.036	0.400
56	6.985	8	14.328	163.88	2.15	2.141	7.272	10.808	0.227	0.300	0.097	0.364
57	7.368	8	14.208	163.26	2.15	2.126	7.392	10.688	0.300	0.414	0.151	0.357
58	4.880	5	14.399	94.86	2.15	2.150	7.201	10.879	0.414	0.414	.000	0.549
59	5.806	5	14.392	94.84	2.15	2.149	7.208	10.872	0.414	0.417	0.004	0.489
60	6.456	5	14.399	94.86	2.15	2.150	7.201	10.879	0.417	0.417	.000	0.455
61	6.273	7	14.376	141.51	2.15	2.147	7.224	10.856	0.417	0.430	0.017	0.408
62	7.160	7	14.368	141.47	2.15	2.146	7.232	10.848	0.430	0.470	0.053	0.374
63	7.973	7	14.392	141.58	2.15	2.149	7.208	10.872	0.596	0.680	0.112	0.347
64	6.414	9	14.392	186.59	2.15	2.149	7.208	10.872	0.680	0.733	0.071	0.365
65	7.280	9	14.304	186.06	2.15	2.138	7.296	10.784	0.733	0.854	0.161	0.340
66	8.006	9	14.080	184.70	2.15	2.110	7.520	10.560	0.854	1.069	0.287	0.330
67	5.703	10	14.320	208.29	2.15	2.140	7.280	10.800	1.069	1.095	0.035	0.385
68	6.816	10	14.360	208.56	2.15	2.145	7.240	10.840	1.095	1.215	0.160	0.340
69	7.672	10	14.240	207.74	2.15	2.130	7.360	10.720	1.215	1.300	0.114	0.319
70	4.709	12	14.400	252.90	2.15	2.150	7.200	10.880	0.720	0.759	0.052	0.405
71	5.972	12	14.280	251.89	2.15	2.135	7.320	10.760	0.759	0.859	0.133	0.352
72	7.278	12	14.240	251.55	2.15	2.130	7.360	10.720	0.859	1.047	0.251	0.310
73	5.726	8	13.600	160.05	2.10	2.100	8.000	10.080	0.010	0.020	0.013	0.460
74	6.882	8	13.504	159.53	2.10	2.088	8.096	9.984	0.020	0.047	0.036	0.413

Table A6

Capped Seawall with Berm Data, Configuration 6

Test No.	Sage Seven Hmo ft.	Nom. Tp sec.	Sage Seven depth ft.	Nom. L ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Rel. Frbd. F/ws
76	5.828	8	14.399	164.25	2.15	2.150	7.201	10.879	0.030	0.096	0.087	0.406
77	7.040	8	14.360	164.05	2.15	2.145	7.240	10.840	0.096	0.152	0.074	0.360
78	7.809	8	14.352	164.01	2.15	2.144	7.248	10.832	0.152	0.226	0.098	0.336
79	5.157	5	14.400	94.86	2.15	2.150	7.200	10.880	0.226	0.227	0.001	0.529
80	6.241	5	14.400	94.86	2.15	2.150	7.200	10.880	0.227	0.228	0.001	0.466
81	6.945	5	14.240	94.48	2.15	2.130	7.360	10.720	0.245	0.282	0.049	0.444
82	6.780	7	14.400	141.61	2.15	2.150	7.200	10.880	0.290	0.298	0.011	0.386
83	7.514	7	14.400	141.61	2.15	2.150	7.200	10.880	0.298	0.320	0.029	0.360
84	8.250	7	14.208	140.78	2.15	2.126	7.392	10.688	0.320	0.440	0.159	0.348
85	6.467	9	14.256	185.77	2.15	2.132	7.344	10.736	0.440	0.476	0.048	0.371
86	7.549	9	14.232	185.62	2.15	2.129	7.368	10.712	0.476	0.557	0.108	0.336
87	8.445	9	14.240	185.67	2.15	2.130	7.360	10.720	0.557	0.690	0.177	0.311
88	6.201	10	14.320	208.29	2.15	2.140	7.280	10.800	0.690	0.710	0.027	0.364
89	7.239	10	14.328	208.34	2.15	2.141	7.272	10.808	0.710	0.788	0.104	0.328
90	7.946	10	14.248	207.80	2.15	2.131	7.352	10.728	0.788	0.878	0.120	0.312
91	4.952	12	14.304	252.09	2.15	2.138	7.296	10.784	0.878	0.898	0.027	0.398
92	5.918	12	14.240	251.55	2.15	2.130	7.360	10.720	0.898	0.985	0.116	0.356
93	6.786	12	14.264	251.75	2.15	2.133	7.336	10.744	0.985	1.103	0.158	0.324

Table A7

Capped Seawall with Wide Berm Data, Configuration 7

Test No.	Gage Seven Hmo ft.	Nom. Tp sec.	Gage Seven depth ft.	Nom. L ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Rel. Frbd. F/ws
121	8.102	9	12.792	176.64	2.05	2.049	8.808	9.272	0.201	0.219	0.024	0.389
122	7.258	7	12.720	134.08	2.05	2.040	8.880	9.200	0.219	0.223	0.005	0.463
123	6.047	5	12.784	90.74	2.05	2.048	8.816	9.264	0.223	0.227	0.005	0.591
124	7.296	8	12.760	155.46	2.05	2.045	8.840	9.240	0.227	0.238	0.015	0.437
125	5.877	12	12.800	238.98	2.05	2.050	8.800	9.280	0.238	0.245	0.009	0.435
126	6.451	10	12.776	197.37	2.05	2.047	8.824	9.256	0.245	0.259	0.019	0.437
127	7.181	9	12.768	176.48	2.05	2.046	8.832	9.248	0.259	0.265	0.008	0.423
128	7.727	8	14.360	164.05	2.15	2.145	7.240	10.840	0.321	0.395	0.098	0.338
129	6.841	8	14.312	163.80	2.15	2.139	7.288	10.792	0.395	0.453	0.077	0.370
130	5.886	8	14.424	164.38	2.15	2.153	7.176	10.904	0.453	0.479	0.035	0.402
131	6.460	5	14.440	94.96	2.15	2.152	7.160	10.920	0.479	0.479	0.000	0.452
132	5.932	5	14.384	94.83	2.15	2.146	7.216	10.864	0.479	0.471	-0.011	0.493
133	5.196	5	14.376	94.81	2.15	2.145	7.224	10.856	0.471	0.472	0.001	0.529
134	7.840	7	14.360	141.44	2.15	2.145	7.240	10.840	0.472	0.524	0.069	0.352
135	7.312	7	14.304	141.20	2.15	2.138	7.296	10.784	0.524	0.553	0.039	0.372
136	6.308	7	14.320	141.27	2.15	2.140	7.280	10.800	0.130	0.147	0.023	0.409
137	6.286	9	14.400	186.63	2.15	2.150	7.200	10.880	0.147	0.180	0.044	0.370
138	7.390	9	14.240	185.67	2.15	2.130	7.360	10.720	0.180	0.266	0.114	0.340
139	8.140	9	14.288	185.96	2.15	2.136	7.312	10.768	0.410	0.537	0.169	0.317
140	7.658	10	14.272	207.96	2.15	2.134	7.328	10.752	0.537	0.562	0.033	0.318
141	7.088	10	14.312	208.24	2.15	2.139	7.288	10.792	0.562	0.714	0.202	0.333
142	6.008	10	14.368	208.62	2.15	2.146	7.232	10.848	0.714	0.730	0.021	0.369
143	6.895	12	14.280	251.89	2.15	2.135	7.320	10.760	0.730	0.864	0.179	0.320
144	5.901	12	14.304	252.09	2.15	2.138	7.296	10.784	0.864	0.943	0.105	0.354
145	4.880	12	14.352	252.49	2.15	2.144	7.248	10.832	0.943	0.960	0.023	0.399

Table A8

Double Capped Seawall with Wide Berm Data, Configuration 8

Test No.	Gage Seven Hmo ft.	Nom. Tp sec.	Gage Seven depth ft.	Nom. Lp ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Rel. Frbd. F/ws
146	6.481	5	14.408	94.883	2.152	2.149	7.192	10.888	0.100	0.120	0.026	0.454
147	8.041	7	14.360	141.439	2.150	2.145	7.240	10.840	0.120	0.135	0.020	0.346
148	7.963	8	14.288	163.675	2.150	2.136	7.312	10.768	0.135	0.182	0.062	0.335
149	8.604	9	14.280	185.912	2.150	2.135	7.320	10.760	0.182	0.265	0.110	0.305
150	7.749	10	14.304	208.180	2.150	2.138	7.296	10.784	0.265	0.352	0.115	0.314
151	6.869	12	14.344	252.426	2.150	2.143	7.256	10.824	0.352	0.456	0.138	0.318
152	5.878	12	14.336	252.359	2.150	2.142	7.264	10.816	0.456	0.510	0.072	0.353
153	7.070	10	14.288	208.071	2.150	2.136	7.312	10.768	0.510	0.555	0.060	0.335
154	7.091	9	14.216	185.526	2.150	2.127	7.384	10.696	0.555	0.616	0.081	0.351
155	6.920	8	14.320	163.841	2.150	2.140	7.280	10.800	0.616	0.655	0.052	0.366
156	7.767	7	14.352	141.404	2.150	2.144	7.248	10.832	0.708	0.725	0.023	0.355
157	5.981	5	14.400	94.864	2.150	2.150	7.200	10.880	0.725	0.725	.000	0.479
158	4.864	12	14.384	252.763	2.150	2.148	7.216	10.864	0.725	0.736	0.015	0.398
159	6.018	10	14.352	208.509	2.150	2.144	7.248	10.832	0.736	0.747	0.015	0.369
160	6.453	9	14.280	185.912	2.150	2.135	7.320	10.760	0.747	0.770	0.031	0.370
161	5.914	8	14.320	163.841	2.150	2.140	7.280	10.800	0.770	0.779	0.012	0.407
162	6.703	7	14.400	141.610	2.150	2.150	7.200	10.880	0.779	0.779	.000	0.359
163	5.194	5	14.400	94.864	2.150	2.150	7.200	10.880	0.779	0.779	.000	0.326

Table A9

Seawall with Beach Breakwater Data, Configuration 9

Test No.	Gage Seven Hmo ft.	Nom. Tp sec.	Gage Seven depth ft.	Nom. L ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Rel. Frbd. F/ws
94	7.648	8	14.280	163.63	2.15	2.135	7.320	10.760	0.133	0.300	0.221	0.345
95	6.016	8	14.280	163.63	2.15	2.135	7.320	10.760	0.300	0.380	0.106	0.405
96	7.035	8	14.264	163.55	2.15	2.133	7.336	10.744	0.380	0.525	0.193	0.365
97	5.162	5	14.344	94.73	2.15	2.143	7.256	10.824	0.525	0.531	0.008	0.533
98	6.042	5	14.272	94.55	2.15	2.134	7.328	10.752	0.531	0.533	0.003	0.485
106	6.809	5	14.400	94.86	2.15	2.150	7.200	10.880	0.041	0.046	0.007	0.439
107	7.175	7	14.368	141.47	2.15	2.146	7.232	10.848	0.046	0.071	0.033	0.373
108	8.011	7	14.320	141.27	2.15	2.140	7.280	10.800	0.071	0.127	0.074	0.349
109	8.481	7	14.280	141.09	2.15	2.135	7.320	10.760	0.127	0.214	0.115	0.333
110	6.998	9	14.344	186.30	2.15	2.143	7.256	10.824	0.214	0.300	0.114	0.347
111	8.106	9	14.200	185.43	2.15	2.125	7.400	10.680	0.300	0.446	0.194	0.322
112	8.403	9	14.208	185.48	2.15	2.126	7.392	10.688	0.470	0.689	0.291	0.314
113	5.750	10	14.400	208.84	2.15	2.150	7.200	10.880	0.689	0.737	0.064	0.378
114	7.330	10	14.240	207.74	2.15	2.130	7.360	10.720	0.737	0.855	0.157	0.329
115	7.856	10	14.216	207.58	2.15	2.127	7.384	10.696	0.855	1.050	0.260	0.316
116	4.658	12	14.280	251.89	2.15	2.135	7.320	10.760	1.050	1.101	0.068	0.416
117	6.026	12	14.312	252.16	2.15	2.139	7.288	10.792	1.101	1.230	0.172	0.348
118	6.733	12	14.272	251.82	2.15	2.134	7.328	10.752	1.230	1.435	0.275	0.325
101	7.168	8	12.792	155.64	2.05	2.049	8.808	9.272	0.580	0.590	0.013	0.440
102	7.516	8	12.792	155.64	2.05	2.049	8.808	9.272	0.590	0.600	0.013	0.427
103	5.106	5	12.776	90.72	2.05	2.047	8.824	9.256	0.600	0.612	0.016	0.662
104	6.047	5	12.784	90.74	2.05	2.048	8.816	9.264	0.612	0.614	0.003	0.591
105	6.254	5	12.792	90.76	2.05	2.049	8.808	9.272	0.614	0.614	.000	0.577
119	5.988	12	12.760	238.62	2.05	2.045	8.840	9.240	0.276	0.290	0.019	0.432
120	7.278	10	12.792	197.49	2.05	2.049	8.808	9.272	0.290	0.300	0.013	0.403

Table A10

Sheet-Pile Seawall with Standard Revetment

Data, Configuration 10

TEST NO.	Gage Seven Hmo ft.	Nom. Tp sec.	Gage Seven Depth ft.	Nom. Lp Gage Seven ft.	SWL1 ft.	SWL2 ft.	Ave. FRBD ft.	Toe Depth ft.	Ovtp. level1 ft.	Ovtp. level2 ft.	Ovtp. rate cfs/ft	Relative Frbd. F/ws
148	5.860	5	13.152	91.724	2.072	2.072	6.256	9.632	0.015	0.015	0.000	0.427
149	7.000	7	13.040	135.570	2.072	2.058	6.368	9.520	0.015	0.145	0.172	0.339
150	7.075	8	13.056	157.098	2.072	2.060	6.352	9.536	0.015	0.425	0.543	0.319
151	7.539	9	12.976	177.817	2.072	2.050	6.432	9.456	0.425	0.919	0.524	0.297
152	7.132	10	12.976	198.828	2.072	2.050	6.432	9.456	0.201	0.550	0.463	0.297
153	6.028	12	13.104	241.699	2.072	2.066	6.304	9.584	0.550	0.982	0.575	0.306
154	6.895	7	13.056	135.643	2.072	2.060	6.352	9.536	0.106	0.218	0.148	0.341
155	6.987	8	12.992	156.745	2.072	2.052	6.416	9.472	0.218	0.387	0.224	0.326
156	7.141	9	12.664	175.808	2.072	2.011	6.744	9.144	0.387	0.595	0.276	0.325
157	6.705	10	12.968	198.770	2.072	2.049	6.440	9.448	0.595	0.777	0.242	0.310
158	7.279	7	12.280	131.999	2.025	2.010	7.128	8.760	0.068	0.114	0.061	0.373
159	7.519	8	12.216	152.380	2.025	2.002	7.192	8.696	0.114	0.281	0.221	0.351
160	7.868	9	12.280	173.292	2.025	2.010	7.128	8.760	0.281	0.487	0.273	0.323
161	7.324	10	12.248	193.462	2.025	2.006	7.160	8.728	0.487	0.605	0.157	0.328
162	6.628	7	12.400	132.573	2.025	2.025	7.008	8.880	0.645	0.645	0.000	0.390
163	6.902	8	12.256	152.610	2.025	2.007	7.152	8.736	0.645	0.728	0.110	0.369
164	6.776	9	12.272	173.240	2.025	2.009	7.136	8.752	0.728	0.860	0.176	0.357
165	6.540	10	12.240	193.402	2.025	2.005	7.168	8.720	0.860	1.064	0.272	0.354
166	6.758	7	12.592	133.483	1.978	2.096	6.816	9.072	0.010	0.039	0.038	0.373
167	NA	8	11.088	145.712	1.978	1.908	8.320	7.568	0.039	0.190	0.200	NA
168	7.351	9	10.624	161.871	1.978	1.850	8.784	7.104	0.190	0.291	0.134	0.426
169	7.045	10	10.856	182.662	1.978	1.879	8.552	7.336	0.291	0.392	0.134	0.410
170	6.451	7	11.424	127.791	1.978	1.950	7.984	7.904	0.392	0.402	0.013	0.457
171	6.566	8	11.480	148.075	1.978	1.957	7.928	7.960	0.402	0.435	0.044	0.427
172	7.035	9	11.520	168.172	1.978	1.962	7.888	8.000	0.435	0.501	0.088	0.389
173	6.796	10	11.488	187.658	1.978	1.958	7.920	7.968	0.501	0.575	0.098	0.386
174	7.026	8	11.584	148.694	1.978	1.970	7.824	8.064	0.575	0.648	0.097	0.403
175	5.523	5	11.648	87.531	1.978	1.978	7.760	8.128	0.040	0.040	0.000	0.559
176	6.602	7	11.576	128.554	1.978	1.969	7.832	8.056	0.040	0.063	0.030	0.441
177	6.724	8	11.568	148.599	1.978	1.968	7.840	8.048	0.063	0.124	0.081	0.415
178	7.190	9	11.400	167.345	1.978	1.947	8.008	7.880	0.124	0.188	0.085	0.390
179	6.782	10	11.008	183.879	1.978	1.898	8.400	7.488	0.188	0.302	0.151	0.412
180	6.158	12	11.512	227.061	1.978	1.961	7.896	7.992	0.302	0.443	0.187	0.385
181	5.183	5	11.648	87.531	1.978	1.978	7.760	8.128	0.429	0.428	0.000	0.584
182	6.194	7	11.560	128.474	1.978	1.967	7.848	8.040	0.428	0.439	0.015	0.461
183	6.546	8	11.576	148.646	1.978	1.969	7.832	8.056	0.439	0.471	0.042	0.423
184	6.627	9	11.656	169.103	1.978	1.979	7.752	8.136	0.471	0.509	0.050	0.397
185	5.411	5	10.888	85.219	1.931	1.930	8.520	7.368	0.045	0.045	0.000	0.628
186	6.065	7	10.896	125.089	1.931	1.931	8.512	7.376	0.045	0.050	0.007	0.512
187	6.656	8	10.832	144.140	1.931	1.923	8.576	7.312	0.050	0.066	0.021	0.462
188	6.925	9	10.784	163.019	1.931	1.917	8.624	7.264	0.066	0.091	0.033	0.435
189	6.823	10	10.336	178.426	1.931	1.861	9.072	6.816	0.091	0.118	0.036	0.448
190	5.297	12	10.872	220.862	1.931	1.928	8.536	7.352	0.118	0.144	0.034	0.465
191	4.824	5	10.896	85.244	1.931	1.931	8.512	7.376	0.144	0.144	0.000	0.677
192	5.637	7	10.896	125.089	1.931	1.931	8.512	7.376	0.163	0.167	0.005	0.537
193	6.243	8	10.888	144.486	1.931	1.930	8.520	7.368	0.167	0.177	0.013	0.479
194	6.436	9	10.816	163.246	1.931	1.921	8.592	7.296	0.177	0.199	0.029	0.454
195	6.269	10	10.988	182.919	1.931	1.930	8.520	7.368	0.199	0.210	0.015	0.442
196	5.189	12	10.656	218.725	1.931	1.901	8.752	7.136	0.210	0.249	0.052	0.485

APPENDIX B: ANALYSIS OF SAVILLE'S DATA

1. In addition to determining overtopping coefficients from the Roughans Point laboratory tests, some additional coefficients were derived from a previous study for use in estimated overtopping rates for the existing north wall at Roughans Point. The previous study was conducted by Saville (1955)* using monochromatic wave conditions on a variety of seawall configurations. While the degree of comparability between monochromatic and irregular wave overtopping tests is not fully understood, the coefficients determined from the earlier monochromatic tests were applied to existing seawall configurations for sheltered locations on Broad Sound (Reaches A through D, Figure 2, main text). Note that the monochromatic coefficients should not be used for locations exposed to the open coast. Monochromatic data trends were also similar to the irregular wave overtopping data trends, and the monochromatic coefficients exhibited logical tendencies. A_q for example, as shown in Table B1, is a measure of the amount of overtopping and tends to increase with increasing water depth, which is what logically should happen.

Table B1

Overtopping Coefficients for Saville's Monochromatic Data

Structure Configuration	Water Depth d_s, ft	Overtopping Coefficients $Q = Q_o e^{C_1 F'}$ *		Configuration Overtopping Rating A_q**
		Q_o, ft^2/sec	C_1	
Vertical wall	0.0	3.47	-10.074	0.0168
	4.5	3.82	-5.762	0.1177
	9.5	10.58	-6.776	0.2045
Riprap 1 on 1.5	0.0	6.88	-11.434	0.0195
	4.5	8.66	-9.751	0.0476
	9.0	18.86	-9.762	0.1033

* The range of F' is from 0.094 to 1.277.
** See paragraph 17.

* References cited in this appendix are included in the References at the end of the main text.

2. The monochromatic wave conditions considered included two seawall configurations at three different water levels. Because of the wide range in water levels, the data were analyzed as six distinct subsets. The structure configurations were a vertical wall and a riprap armored seawall with a slope of 1 on 1.5. Both structures had 1 on 10 fronting slopes, and the water depths tested were deep at the toes of the structures.

3. In Saville's test report (Saville 1955), the local wave height near the structure is not given. Therefore, the local wave height had to be calculated in order to develop coefficients as consistent as possible with those determined from the irregular wave tests. Using the deepwater height and period, the wave height and wave length in a depth of 13.5 ft was calculated using linear wave theory. A depth of 13.5 ft represents a water depth within the range used to develop the overtopping coefficients for the irregular wave tests. The estimated wave height and wave length in 13.5 ft of water was used to calculate the dimensionless freeboard F' (see Equation 1). The range of wave heights was from 2.75 to 13.32 ft, and the range of wave periods was from 2.96 to 15.00 sec. The overtopping coefficients from Saville's tests are given in Table B1. These monochromatic wave coefficients cannot be compared directly to the coefficients given in Table 1 (in main text) for irregular waves; however, they can be used to evaluate the relative effectiveness of the six structure configurations/swl permutations.

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